STUDIES ON INTERACTION OF AIR POLLUTANTS AND ROOT-KNOT NEMATODES ON SOME PULSE CROPS

ABSTRACT

OF

THE THESIS SUBMITTED FOR THE DEGREE OF

Doctor of Philosophy

IN

BOTANY

SANJIV KUMAR SINGH

DEPARTMENT OF BOTANY
ALIGARH MUSLIM UNIVERSITY
ALIGARH (INDIA)

1989

ABSTRACT

Air pollution is a relatively new factor in agriculture, causing stresses on crop growth and their productivity. Air pollution effects on agricultural crops has drawn attention of investigators rather late, and the various aspects of air pollution-agricultural crop relations have gained little study, especially in India. The present studies were undertaken to examine interaction of air pollutants and root-knot nematodes and their interactive effects on different parameters of growth and productivity of chickpea and lentil, two important pulse crops in India. The interactive effects on root-knot nematodes which commonly attack the pulse crops, and root-nodule bacteria forming nodules on roots for symbiotic nitrogen fixation have also been assessed. The experiments have been conducted both in ambient and in artificial exposure conditions. For the studies on ambient air pollution, a thermal power plant located at Kasimpur, about 15 km away from the campus of the Aligarh Muslim University using coal as fuel was selected as pollution source of air pollutants. Artificial exposure studies were done in dynamic state exposure chambers using varying concentrations of SO_2 and O_3, singly and in mixture. Interaction of flyash, one of the major air pollutants originating from the thermal power plant,

was examined using ambient polluted soil and soil artificially amended with the flyash. The interaction of simulated acid rain was also studied in artificial treatment conditions. In addition to interaction studies, effects of pollutants on seed germination and post-emergence mortality of seedlings of chick-pea and lentil, juvenile hatching of root-knot nematodes, M. incognita and M. javanica and in vitro growth of Rhizobium were also examined.

For the interaction studies, two pulse crops chick-pea, Cicer arietinum L (cv. T-3) and lentil Lens culinaris Medic. (cv. T-36) were invariably used as test crops and at the termination of the experiments, the interactive effects were assessed using plant growth (length, fresh and dry weights of shoot and root), yield (flowering and fruiting), leaf pigments (chlorophyll a,b and total chlorophyll), seed proteins (soluble and insoluble) and leaf epidermal characters (number of stomata, size of stomata and stomatal aperture, and number and length trichomes and trichome-hydathodes) as parameters. Rhizobium inoculation, wherever required according to the design of the experiments, was done at the time of seed sowing. Inoculum level for M. incognita and M. javanica in the studies was consistently 1000 J_2/pot and inoculations were done 30 days after seed sowing.

Air pollution monitoring data showed that in the vicinity of the Thermal Power Plant, Kasimpur, SO_2, NO_2 and SPM were present in the ambient air and their concentration was greater at 1/2 km site (K_1) than 2 km site (K_2) from the pollution source. The particulate matter deposition was also greater at the closer site than the distant site. Survey conducted around the Thermal Power Plant, Kasimpur showed that crop fields of chick-pea and lentil were infected with M. incognita and M. javanica. Root-knot disease on the crops appeared to be influenced by the ambient air pollution. The disease incidence on the crops and gall formation and eggmass production of the root-knot nematodes was related to the air pollution level which depended on direction and distance from the pollution source. Root galling and eggmass production increased with the decreasing pollution level. Root nodulation by Rhizobium on the crops was also found to be affected by the pollution and nodulation decreased with the increasing pollution level. The air pollution also caused early death of root nodule and more non-functional nodules were recorded under the pollution stress. Root nodules were also found infected by the root-knot nematodes, which decreased with the increasing air pollution level. But at a very low level of pollution, greater infection of root nodules occurred.

Air pollution induced symptoms on the foliage of chick-pea and lentil were detected. The intensity of the symptoms was also pollution level dependent. The lentil plants showed more sensitivity than chick-pea.

The studies on the effect of ambient air pollution on seed germination and post-emergence mortality of seedlings conducted at the two sites, 1/2 km and 2 km away from the pollution source showed that ambient air pollution supressed seed germination of chick-pea and lentil, and induced greater post-emergence mortality of seedlings of both the crops. The suppression in seed germination of chick-pea was greater than lentil while post-emergence mortality of lentil seedlings was greater than chick-pea. The seed germination and post-emergence mortality of seedlings were correlated with the pollution level.

Interaction studies on ambient air pollution, Rhizobium and M. incognita/M. javanica on chick-pea and lentil and their interactive effects on the crops, conducted at both the sites in polluted area showed that ambient air pollution suppressed plant growth and yield; reduced leaf pigments and seed proteins and influenced various leaf epidermal characters. Number of stomata, size of stomata and stomatal aperture and number and length of trichome-hydathodes (only in chick-pea) were adversely

affected, while the number and length of trichomes on leaf surfaces showed an increase on pollution stressed plants. The ambient air pollution suppressed root nodulation by Rhizobium and gall formation and eggmass production of root-knot nematodes, M. incognita and M. javanica. The infection of root nodules by root-knot nematodes was also reduced.

Rhizobium favoured plant growth and other considered parameters like yield, leaf pigments, seed proteins and some leaf epidermal characters but number and length of trichomes on leaf surfaces of both the crops were reduced. M. incognita and M. javanica, on the otherhand, suppressed plant growth and other parameters but increased the number and size of trichomes on the leaves. M. incognita was found to be more pathogenic than M. javanica to both chick-pea and lentil. Rhizobium and M. incognita/M. javanica exhibited mutually inhibitory influences and interacted antagonistically. Their antagonistic interaction was reflected on various considered parameters of the crops. The interaction between ambient air pollution and Rhizobium was also antagonistic. As a result, root nodulation was invariably suppressed. The ambient air pollution and M. incognita/M. javanica alone or in presence of Rhizobium interacted antagonistically resulting in suppression of root galling and eggmass production. These interactions between the ambient

air pollution and root-knot nematodes influenced the considered plant growth, yield and other parameters accordingly.

Impact of SO_2, O_3 and SO_2+O_3 on seed germination and post-emergence mortality of seedlings of chick-pea and lentil was studied under artificial exposures using two different concentrations, 0.1 ppm and 0.2 ppm singly and in combination. Influence of the pollutants on *in vitro* growth of chick-pea and lentil strains of *Rhizobium* and juvenile hatching of *M. incognita* and *M. javanica* were also examined. The interaction of both the concentrations of air pollutants (SO_2 and O_3) singly and in combination with *Rhizobium* and *M. incognita*/*M. javanica* and their interactive effects on the various parameters of the pulse crops were studied in the controlled exposure conditions in exposure chambers. The exposure of air pollutants started at three different times in relation to nematode inoculation (1000 J_2/pot), i.e exposure started one week before nematode inoculation (pre-inoculation exposure); exposure started at the time of nematode inoculation (simultaneous-inoculation exposure); and the exposure started one week after nematode inoculation (post-inoculation exposure).

SO_2,O_3 and SO_2+O_3 in artificial exposure inhibited seed germination of chick-pea and lentil and increased

the post-emergence mortality of the seedlings. The effects were related to the concentration of the pollutants. 0.2 ppm being more effective than 0.1 ppm. The inhibition of seed germination was greater in chick-pea but post-emergence mortality of seedlings was greater in lentil. In vitro growth of Rhizobium was inhibited by SO_2, O_3 and SO_2+O_3 mixture. SO_2 was more suppressive for the chick-pea strain of Rhizboium while O_3 was more inhibitory to lentil strain of Rhizobium. SO_2 and O_3, separately and in mixture also suppressed the juvenile hatching of M. incognita and M. javanica. The inhibition was greater for M. incognita. The adverse effects on Rhizbium growth and juvenile hatching of the nematodes were greater in the higher concentrations of the pollutants.

SO_2 and O_3, singly and in mixture adversely affected plant growth, yield, leaf pigments, seed proteins and leaf epidermal characters of chick-pea and lentil. But trichomes on the leaves were promoted by the air pollutants. O_3 was more toxic than SO_2 and the effect of SO_2 and O_3 mixture was greater than the individual pollutants at the same concentration. But SO_2 and O_3 showed antagonistic interaction and antagonistic interactive effects on various parameters at both the concentrations.

SO_2 and O_3 singly and in mixture suppressed root nodulation by Rhizobium and root galling and eggmass production of M. incognita and M. javanica. Root galling and eggmass production was highest in post-inoculation exposure and lowest in simultaneous inoculation exposures of plants. In pre-inoculation exposures of plants, root galling and eggmass production was greater than simultaneous inoculation exposure and was smaller than post-inoculation exposure of plants. Root nodulation was highest in simultaneous inoculation exposures and lowest in post-inoculation exposures of plants. The infection of root nodules by nematodes was also adversely affected and was highest in pre-inoculation exposure and lowest in simultaneous inoculation exposure of plants. The pollutants interacted antagonistically with Rhizobium, M. incognita and M. javanica singly or in combination and suppressed their effects on various parameters, studied on both the crops.

Seed germination and post-emergence mortality of seedlings of chick-pea and lentil, growth of chick-pea and lentil strains of Rhizobium and juvenile hatching of M. incognita and M. javanica were examined in the acidic media of pH 6, 5, 4, 3.2 and 2.5. The interaction

of simulated acid rains of pH 5 and 3.2 with Rhizobium and M. incognita/M. javanica and their interactive effects on various plant growth, yield and others parameters were studied on chick-pea and lentil. The treatment of acid rain was started at three different times in relation to nematode inoculation i.e. pre-, simultaneous and post-inoculation exposures.

Poor seed germination and greater post-emergence mortality of seedlings of chick-pea and lentil occurred in acidic range pH. These were correlated with acidity level. Inhibition of seed germination of chick-pea was greater than lentil while post-emergence mortality of seedlings was greater in lentil than chick-pea.

The acidity of the medium suppressed in vitro growth of Rhizobium and the growth showed a direct correlation with the pH. Chick-pea strain of Rhizobium was more sensitive than the lentil strain. Complete inhibition of growth of chick-pea and lentil strains occurred at pH 3.2 and 2.5 respectively. Juvenile hatching of M. incognita and M. javanica was suppressed by the pH in acidic range and was correlated with the acidity level.

Simulated acid rains retarded plant growth of chick-pea and lentil and reduced yield, leaf pigments,

seed proteins and some of the considered leaf epidermal characters. Trichomes response was favourable to their application and their number and length increased.

Root nodulation by Rhizobium on both the crops and root galling and eggmass production of M. incognita and M. javanica were inhibited by the acid rains. In the study, on all kinds of influences on various parameters, acid rain of pH 3.2 was consistently more effective than of pH 5. Root galling and eggmass production due to acid rain treatment in relation to nematode inoculation was highest in post-inoculation exposure and lowest in pre-inoculation exposure of plants. Root nodulation and infection of root nodules by the nematodes were highest in pre-inoculation exposure and lowest in post-inoculation exposure of plants.

Simulated acid rain interacted antagonistically with Rhizobium and M. incognita/M. javanica individually and in combination, and as a result both the organisms were suppressed and the interaction reflected in various parameters, considered in the study.

The impact of flyash polluted soil was studied by collecting the soils from 1/2 km (S_1) and 2 km (S_2)

away from the stack of the Thermal Power Plant, Kasimpur which were also the sites for ambient air pollution study. For artificial amendment of the unpolluted soil, flyash was collected from the thermal power plant. The unpolluted soil was amended with the flyash by mixing 10,20 .....100% flyash.

Physico-chemical analysis of the ambient flyash polluted soils showed that addition of flyash emanating from the thermal power plant had improved porosity, water holding capacity, conductivity, cation exchange capacity, organic matter, sulphate, carbonate and bicarbonate conents of the soils. Flyash lowered the soil pH.

Seed germination of chick-pea and lentil were inhibited and greater post-emergence mortality of the seedlings occurred in ambient flyash polluted soils. The inhibition in seed germination was greater in chick-pea than lentil while post-emergence mortality of lentil seedlings was greater than lentil. In these respects, soil of 1/2 km site (S_1) was more effective than 2 km soil, because flyash concentration was greater in 1/2 km soil. Seed germination of chick-pea and lentil in flyash amended soil showed stepwise decrease with the increasing concentration of flyash. Mortality of the seedlings also

increased with the increasing concentration.

Juvenile hatching of M. incognita and M. javanica was inhibited in the ambient flyash polluted soils. The inhibition was greater for M. incognita than M. javanica. Juvenile hatching of M. incognita and M. javanica showed a stepwise increase in inhibition in the flyash amended soil with the increasing flyash concentration. The hatching was completely suppressed at 80 and 90% flyash level, respectively.

Flyash pollution of the soil increased the plant growth and yield and other considered parameters, in relation to leaf pigments, seed proteins and leaf epidermal characters. However, a decrease was observed in the number and length of trichomes on the leaves. Effects of 1/2 km soil on all the parameters was invariably greater than 2 km soil. In the study on impact of flyash amended soils where various levels of flyash (10,.....100%) were used, similar effects occurred on plants of the crops. An increase in their growth and other considered parameters occurred upto 50% for chick-pea and 60% for lentil. Beyond these levels, flyash exhibited toxic effects on plants. Flyash was also toxic to Rhizobium and inhibited root nodulation. This inhibition was related to the level of

flyash. Inhibition on root nodulation was greater in 1/2 km soil than 2 km soil. A stepwise decline in root nodulation was observed with increasing level of flyash and it was completely inhibited at 90% in chick-pea and 80% in lentil. Flyash, however, favoured the gall formation by M. incognita and M. javanica but the eggmass production by both the species of Meloidogyne was inhibited by the flyash in the ambient flyash polluted soil. The effects of 1/2 km soil was greater than 2 km soil on gall formation and eggmass production by the nematodes. Similar effect of flyash was also observed in the amended soils. Gall formation by M. incognita and M. javanica was favoured by flyash upto 50%. Further increase in flyash level caused inhibition of root galling. But flyash suppressed eggmass production of both M. incognita and M. javanica and suppression became greater with the increasing concentration. Flyash completely inhibited the root galling and eggmass production at 90 and 70% level, respectively. Flyash at lower levels (upto 50%) favoured the infection of nodules by the nematodes. Flyash also suppressed the favourable effects of Rhizobium and unfavourable effects of M. incognita and M. javanica, gradually with the increasing concentration, indicating antagonistic interaction and this reflected in all the considered parameters.

It appears from the study that overall impact of gaseous air pollutants originating from the Thermal Power Plant, Kasimpur are harmful for the crops like chick-pea and lentil. The air pollutants are also harmful for root nodulation by Rhizobium and at the same time suppress the disease caused by root-knot nematodes. Though some benefit is derived by the plants through the suppression of root-knot nematodes, the crops still suffer from air pollution stress. Similar pattern in response of the crop plants, Rhizobium, root-knot nematodes was also observed in artificial treatment conditions. The simulated acid rain also had similar impacts. Flyash, originating from the thermal power plant, at the lower levels in soil is beneficial for the crop plants but it is harmful to Rhizobium as well as for eggmass production of the root-knot nematodes but favours root galling. But at higher levels it becomes harmful to the crop plants, Rhizobium and root-knot nematodes. The overall interaction between root-knot nematodes and studied air pollutants is antagonistic for the root-knot nematodes and Rhizobium on the crops and the interactive effects are, in general, harmful for the crops.

STUDIES ON INTERACTION OF AIR POLLUTANTS AND ROOT-KNOT NEMATODES ON SOME PULSE CROPS

THESIS SUBMITTED FOR THE DEGREE OF

Doctor of Philosophy

IN

BOTANY

SANJIV KUMAR SINGH

DEPARTMENT OF BOTANY
ALIGARH MUSLIM UNIVERSITY
ALIGARH (INDIA)

1989

TO MY PARENTS

Dr. M. WAJID KHAN
M Sc (Ban), Ph D (Alig), F L S , F P S I
READER
Principal Investigator
CSIR Project—Airpollution-animate plant pathogen interactions
ICAR Project—Root-knot nematodes
UGC Project—Cucurbit powdery mildews

Plant Pathology and Plant Nematology Laboratories

DEPARTMENT OF BOTANY

ALIGARH MUSLIM UNIVERSITY
ALIGARH-202 002, INDIA

Dated.....July 7, 1989.....

CERTIFICATE

This is to certify that Mr. Sanjiv Kumar Singh has worked in this department as a Research Scholar under my supervision and guidance. His work on "Studies on interaction of air pollutants and root-knot nematodes on some pulse crops" is upto-date and original. He is allowed to submit his thesis for consideration of the award of the degree of Doctor of Philosophy in Botany.

(M.Wajid Khan)
Research Supervisor

ACKNOWLEDGEMENTS

"In the name of Almighty God", the author wishes to express his sincere gratitude to Dr. M.Wajid Khan, Reader, Department of Botany, Aligarh Muslim University, Aligarh, India, his research supervisor for suggesting the problem, active guidance, critical suggestions, keen interest and encouragement throughout the development of the thesis research.

The cooperative attitude of Prof. Khalid Mahmood, Chairman, Department of Botany, Aligarh Muslim University, Aligarh in providing necessary facilities is greatly appreciated.

The author is indebted to Prof. Abrar M. Khan, Professor Emeritus, for encouragement and affection during his research work.

The author is thankful to the University Grants Commission, New Delhi for awarding a research fellowship, through National Educational Test, for carrying out the research work.

Sincere appreciations are extended to Prof.(Emeritus) J.N. Sasser and Prof. (Mrs.) H. Hirschmann, Department of Plant Pathology, North Carolina State University,

Raleigh, N.C., U.S.A. for providing Plant Nematology Training for sometime in 1986 and 1988 and sparing necessary literature; to Prof. R.A. Reinert and Prof. K.R. Barker, Department of Plant Pathology, North Carolina State University, Raleigh, N.C., U.S.A. for providing the literature on Air Pollution and Plant Nematology. He is also thankful to Prof. W.W. Heck, Department of Botany, North Carolina State University, Raleigh, N.C., U.S.A., the Research Leader, Air Quality Research Unit, South Atlantic Area for providing the library facility. The help and assistance of Mrs. Jeanie Hartman, the Librarian is also greatly acknowledged.

The help and cooperation extended by the friends, specially Mr. Merajun Nabi throughout the preparation of thesis is also gratefully appreciated.

The author would like to express his indebtedness to his parents and other family members for their encouragement, sacrifice, patience, and support throughout his studies.

TABLE OF CONTENTS

INTRODUCTION

With the evolution of our civilization, rapid growth of industries and urban areas were necessary and foremost requirements for the betterment of human life. But this is being accomplished by neglecting the natural environment and hazardous substances originating from human activities are being continuously added to it. This is gradually assuming enormous proportion throughout the world but in developing countries the condition is more worse because of limited resources, expensive technologies and imperfect implementation of legislations for the pollution control. Air which is necessary for all is most affected. Polluted air affects both non-living objects and living organisms. The air pollution is also affecting the stratospheric ozone which serves as protective layer from the space radiation. Air pollution also creates problem of acid through atmospheric precipitation. The intensity of all these problems of air pollution differs from place to place. Particulate air pollutants are the major problems in developing countries while in developed countries gaseous air pollutants and acid rain are more important. Among the gaseous air pollutants, SO_2, NO_x, CO and CO_2 are major air pollutants in developing countries. In metropolitan cities of the developing countries PAN and O_3 are also present but in lesser quantities than the developed countries.

The pollutants released in the atmosphere cause stress on the plants directly and indirectly. Since over 90% of the plant weight is derived from the atmosphere, the air quality is directly related to the plant growth. Air pollution stress may lead to reduced yield. Significant reduction in yield can result without visible sign on the plants. However, a number of air pollutants induce various kinds of symptoms on agricultural, horticultural and forest plants. In U.S.A., it was estimated by the Environmental Protection Agency that in 1976 annual losses to agricultural production caused by diminished air quality was around 2.9 billion dollars. Air pollutants are reported to cause yield losses in soybean, peanut, cotton, tobacco, vegetable crops, ornamentals and other different kinds of plants (Heck et al. 1986).

Root-knot nematodes (Meloidogyne species) as plant pathogens are of international significance. They are ubiquitous in distribution and readily attack agricultural crops all over the world. Of nearly 70 species of Meloidogyne described so far, 4 species viz., Meloidogyne incognita (Kofoid and White) Chitwood, M. javanica (Treub) Chitwood, M. arenaria (Neal) Chitwood and M. hapla Chitwood are recognised as major species as they are most common and damaging (Taylor et al., 1982). The average crop yield loss is estimated to about 25% with damage in the individual fields ranging as high as 60% (Sasser, 1980; Sasser and Carter,

1982). They induce galling on the roots and their saccate sedentary females find feeding sites in the stelar region of the roots and by establishing intimate host-parasite relationship induce development of giant cells around their necks which serve as their source of nutrition. The feeding of nematodes has great impact on the host physiology. The extensive anatomical and physiological changes within the host impairs the various physiological functions (Lewis, 1987; Wallace, 1987; Wilcox-Lee and Loria, 1987).

Root-knot nematodes interact with a number of fungal, bacterial and viral plant pathogens. Intractive effects are generally at disadvantage to the host. (Powell,1971a, 1971b; Taylor 1979; Khan, 1984; Sikora and Carter,1987).

Interactions of root-knot nematodes with nodule forming bacteria have been studied on some leguminous crops (Huang, 1987). The importance of symbiotic nitrogen fixation by nodule forming bacteria of the genera Rhizobium and Bradyrhizobium (earlier Rhizobium japonicum) are well known for many years. However, the role of root-knot nematodes in the symbiosis between bacteria and legumes is much less well known. Root-knot nematodes, legumes and bacteria are all inter-connected in complex ways. It is established that the concurrent nematode infection reduce the total benefit from the nitrogen fixing bacteria (Lehman et al., 1971; Taha and Raski, 1969). Environmental conditions also

affect interaction in this system (Dropkin, 1980).

As air pollutants including acid rain affect plants directly or indirectly, it is plausible to expect that organisms, parasitic or non-parasitic associated with the plants will also be influenced in some way. Various air pollutants affect symbiotic nitrogen fixation at different levels. In general, N-fixation is inhibited resulting from reduction in the nodulation and suppression in bacterial population because of impact of air pollutants on plants. Ozone, sulphur dioxide, particulate matters and acid rain have been found to suppress N-fixation by the species of Rhizobium and Bradyhizobium (Tingey and Blum, 1973; Shriner and Johnston, 1981).

There are a few reports indicating influence of air pollutants on plant parasitic and saprobic nematodes but little work has been done on this aspect. Exposures of soybean plants, inoculated with nematodes, to O_3 and O_3-SO_2 mixture caused inhibition of reproduction and development of Heterodera glycines and Paratrichodorus minor but Belonolaimus longicaudatus remained unaffected. On the other hand, reproduction of Pratylenchus penetrans was enhanced, when exposed to SO_2 in comparison to charcoal filtered air control or to O_3. Nodulation in plants parasitised by B. longicaudatus and P. minor was inhibited, but in plants parasitised by P. penetrans, no such effect was observed (Weber et al., 1979). In a study on interaction

of O_3 and P. penetrans, negative effect of O_3 was enhanced in the presence of P. penetrans (Shew et al., 1982). Tobacco plants infected with root-knot nematode, Meloidogyne hapla are reported to become more susceptible to ambient ozone (Bisessar and Palmer, 1984).

In India, air pollution through industries is becoming increasingly common. Thermal power plants, oil refineries and other small industrial units using coal or oil as fuel are major sources of air pollution in India. A variety of crops are grown around such industries, which might suffer a great loss in case one or other disease become more aggressive under specific pollution conditions. A thermal power plant in Kasimpur situated in Aligarh district in the State of Uttar Pradesh (India) about 15 km from the Aligarh Muslim University campus within the parallels 27° 29' and 28° 11' north latitude and 77° 29' and 78° 38' east longitude at 195 m above sea level is known to cause air pollution in the area. Impact of air pollutants emanating from this thermal power plant on growth characteristics and anatomical features of some plants have been studied (Ghouse and Amani, 1978; Ghouse and Khan, 1978). Interactions of air pollutants and plant parasitic nematodes have not received the attention of investigators in India and only a few attempts have been made in some developed countries. The impact assessment of air pollution on plants when they are infected with root-knot nematodes is the main objective

of the present study.

Pulse crops, one of the most important crop plants throughout the world, are the major source of protein to the vegetarian population particularly in India. Pulse crop plants are symbiotically associated with N-fixing bacteria, Rhizobium species and Bradyrhizobium japonicum, which develop nodules on the root system. Pulse crops are also frequently infected by root-knot nematodes (Meloidogyne species).

In the present study, individual and interactive effects of air pollutants, root-knot nematodes and root nodule bacteria on some pulse crops like chick-pea (gram) (Cicer arietinum L.) and lentil (Lens culinaris Medic.) have been examined both in ambient condition around the Thermal Power Plant, Kasimpur and in glasshouse under artificial treatments. The effects of their interactions on root-knot nematodes in relation to root galling and eggmass production and root nodule bacteria in relation to root nodulation have also been assessed Other aspects taken into consideration are given in respective sections in the thesis. The following five experiments were conducted and each is presented in the thesis separately as a section with independent brief introduction, materials and methods, results, discussion and summary. The literature review and literature cited for all the sections are given jointly.

Section I	Impact of ambient air pollution on root-knot disease and root nodulation on chick-pea and lentil in the vicinity of the Thermal Power Plant, Kasimpur.
Section II	Interaction of ambient air pollution, root-knot nematodes and root nodule bacteria on chick-pea and lentil.
Section III	Interaction of $SO_2/O_3/SO_2$-O_3 mixture, root-knot nematodes and root nodule bacteria on chick-pea and lentil.
Section IV	Interaction of simulated acid rain, root-knot nematodes and root nodule bacteria on chick-pea and lentil.
Section V	Interaction of ambient flyash polluted soil/ flyash amended soil, root-knot nematodes and root nodule bacteria on chick-pea and lentil.

LITERATURE REVIEW

Studies on inter-relationship between air quality and agricultural plant ecosystem are necessary in order to improve the yield of agricultural crops, as suggested by Heck (1982), mainly because the phytotoxic air pollutants, alone or in mixtures, are responsible for substantial yield losses in several crops. Air pollutants are now of great concern to agricultural scientists, because they injure plant foliage, significantly alter their growth and yield and change the quality of the marketable plant products. The air pollutants are also supposed to increase or decrease the plant diseases caused by biotic plant pathogens (Heagle, 1973).

Air pollution is a source-transport-effect phenomenon and as such is analogous in many ways to the plant disease. To obtain a clear understanding of how air pollutants affect plants, it is important to know what are compounds that damage plants and where and how they originate. Broadly the air pollutants are of two types (Wood, 1968):

1. Primary pollutants
2. Secondary pollutants

Primary pollutants are those that originate at the source in a form toxic to plants, e.g. SO_2, HF, NH_3, CO,

CO_2, etc. Secondary pollutants are the result of reactions between pollutants originating from the source and other atmospheric factors e.g. PAN, O_3, acid rain. On the basis of their physical appearance, the air pollutants can also be grouped into two categories - gaseous and particulate air pollutants. The most common gaseous air pollutants injurious to plants are O_3, PAN, SO_2, Cl_2, C_2H_6, HF, H_2S, NOx, etc. and the major particulate air pollutants include coal dust, flyash, cement dust, soil dust particles etc. Some primary air pollutants like NOx, SO_2 released into the atomosphere, when come in contact with the water and atmospheric precipitation are converted into the acids and fall down. This condition of environmental pollution is called 'Acid rain' (Likens and Bormann, 1974). According to Das (1986) acid rain is the most acute and severe problem in developed countries, while in the developing countries acid rain problem is not so serious. The particulate air pollutants are the major problem in developing countries. In India, 40-44% of air pollutants are particulate matters and these are extremely troublesome, posing a great threat to plants and other living beings (Das, 1986).

AIR POLLUTION EFFECTS ON PLANTS

Study of plant diseases caused by air pollution began in the 19th century (Heagle, 1973). As the pathogenic diseases, the extent and nature of injury or damage caused by air pollutants is determined by genetic and environmental

factors of plant as well as by level and duration of exposure to pollutants, the terms injury and damage are often used interchangeably (Guderian et al., 1960). The designation pathogen is given to the living inducers of diseases by many pathologists. But diseases induced by abiotic factors e.g. air pollutants, drought, extremes of temperature etc. have many features in common with those induced by biotic pathogens. For this reason, Cowling and Horsfall (1979) preferred to use term 'pathogen' to denote any inducer of disease. Several workers have reported the effects of different air pollutants on the plants. These pollutants affect physiology and biochemistry of plants resulting in the visible symptoms like chlorosis, necrosis, early senescence, stunting and several other symptoms depending upon the types of air pollutant involved (Darley and Middleton, 1966; Brandt and Heck, 1968; Barret and Benedict, 1970). The plant sensitivity and resistance to air pollutants is altered when the concentration and duration of exposure exceed the plant's genetic capability to withstand the stress (Reinert et al., 1982).

GASEOUS AIR POLLUTANTS (PRIMARY TYPE)

Sulphur dioxide (SO_2)

Sulphur dioxide, a pollutant known for more than 100 years to be toxic to plants is emitted from the combustion of coal, production, refining and utilization of petroleum and natural gas, manufacturing and industrial utiliza-

tion of sulphuric acid and sulphur and the smelting and refining of ores, especially of copper, lead, zinc and nickel. The combustion of coal represents the major source of SO_2 and the amount of SO_2 emitted depends upon sulphur content of the coal, among the other things. The sulphur content of the coal varies from 1% to 6% of the total weight. The coal burning power plants represent the most important single source of SO_2 (Wood, 1968). The concentration of sulphur dioxide at ground level depends upon the amount and concentration (s) of emission, distance from the source and meteorological and topographical conditions. In general, SO_2 concentration decreases rapidly with distance from the source and with increased air movement. SO_2 concentration near point sources, such as coal burning power plants and smelters, with little or no pollution control equipment, may be high as 1-3 ppm. In large urban areas SO_2 concentration may range from 0.05-0.40 ppm (Heagle, 1973).

In general, SO_2 causes several types of symptoms on plants and plant parts. It enters through the stomata in the mesophyll tissue of the leaves and reacts with water to produce sulphite ion which is slowly oxidized to sulphate ion. The sulphate ion may then be utilized by the plant as nutritional sulphur and converted to organic form (Thomas et al., 1944). The sulphite and sulphate ions are toxic to plant cells when present in excessive amounts. The sulphite ions are, however, about 30 times more toxic than the

sulphate ions (Thomas et al., 1943). Due to the SO_2, two general types of markings designated as chronic markings and acute markings, appear depending upon the accumulation of sulphite ions. The chronic type markings are general chlorotic appearance of the leaf, mild chlorosis, yellowing of leaf and silvering or bronzing of the under surface. In some plants white type of chronic markings and appearance of red, brown or black coloured patches on the leaves are seen (Barret and Benedict, 1970). Acute injury resulting from the absorption of lethal quantities of SO_2 appears as marginal or interocostal areas of dead tissue. These areas at first show a grayish-green water-soaked appearance but on drying become bleached ivory in colour. After a period of time, the dead or necrotic areas may fall out leaving a very ragged appearance on the leaf. When the major portion of the leaf is so injured, an abscission layer is often formed at the base of the petiole and the leaf is shed (Barrett and Benedict, 1970). At low concentration, it causes chlorosis of leaves without formation of necrotic lesions and the veins characteristically remains green (Darley and Middleton, 1966; Agrios, 1978).

As SO_2 enters through stomata, factors that affect stomatal opening influence the response to plants to SO_2 (Thomas, 1951, 1961; Negherborn, 1966; Daines, 1968). Resistance of plants to SO_2 is also governed by soil moisture (Zimmerman and Crocker, 1934). When the leaves are turgid,

they are more sensitive to SO_2 than the wilted, since wilted plants are likely to have closed stomata. Thus, soil moisture stress greatly reduces the sensitivity of plants to SO_2. Atmospheric humidity is also an important factor related to SO_2 sensitivity of plants because it regulates stomatal opening (Thomas et al., 1943). With high humidity, plants show greater SO_2 sensitivity. Low concentrations of SO_2 also injure epidermal and gaurd cells leading to increased stomatal conductance and greater entry of SO_2 in plants (Black and Unsworth, 1980). In some plants stomatal conductance is, however, reduced during SO_2 exposure and this reduction might be one mechanism of resistance (Kobriger et al., 1984; Winner and Monney 1980; Bonte et al., 1977). The stomatal closure may be related with high SO_2 concentrations and opening to low concentrations (Unsworth and Black, 1981). Generally, SO_2 reduces net photosynthesis in all plants at all concentrations but dark respiration and transpiration are increased. Short and long term exposures have similar effects in this respect (Black and Unsworth, 1979; Mc Laughlin, et al., 1979; Takemoto and Noble, 1982; Saxe, 1983a). Plants generally show rapid recovery of these processes after termination of exposure lasting upto several days.

The effects of SO_2 on the enzyme systems and metabolic processes have been studied by several workers who observed changes in the activities of many enzymes. These changes are affected by SO_2 concentration,plant species,plant

age and environment. In some cases, enzyme activity is increased by exposure of the plants to low levels of SO_2 and decreased by higher concentrations (Horsman and Wellburn, 1977; Soldatini and Ziegler, 1979; Wyss and Brunold, 1980; Pierre and Queiroz, 1982; Tanaka et al., 1982). Plant metabolism is affected by SO_2 in a variety of ways. SO_2 stimulates phosphorus metabolism (Plesnicar, 1983) and reduces foliar cholorophyll concentration (Pandey and Rao, 1978; Lauenroth and Dodd, 1981). Carbohydrate levels are increased by low concentration of SO_2 and decreased by higher concentrations (Kozoil and Jordon, 1978). In soybean when exposed to SO_2 significant reduction in yield was found due to loss in both seed weight and number of seeds produced by the plants, while seed quality was less affected. Although at higher exposure levels protein contents decreased slightly and concentrations of some mineral elements were altered (Sprugel et al., 1980).

SO_2 altering the physiology and biochemistry of plants affects their growth, development and productivity significantly. The effects of SO_2 in both glasshouse and ambient air on the plants like wheat, soybeans, groundnut, maize, alfalfa, tomato, snap-bean, tobacco, cucumber etc. have been studied by several workers (Laurence, 1970; Lockyer and Cowling, 1981; Lotstein et al., 1983; Mishra, 1980; Mejstrick, 1980; Pandey and Rao, 1978; Saxe, 1983b, Sprugel et al., 1980).

Oxides of Nitrogen (NOx)

Nitric oxide (NO) and nitrogen dioxide (NO_2) are the two significant gases in the nitrogen oxide group of air pollutants which are produced primarily by high-temperature combustion (Taylor and MacLean, 1970). Nitrogen oxides are produced from the oxygen and nitrogen in the air by hot combustion sources, such as open fires, furnaces and automobile combustion chambers. Combustion of petroleum products are the major source of NOx. In this process nitric oxide is oxidised to nitrogen dioxide (Benedict and Breen, 1955; Agrios, 1978). Nitrogen dioxide in concentrations of 2-3 ppm causes bleaching of plants similar to that caused by SO_2 and it also produces necrotic lesions and excessive defoliation (MacLean et al., 1968; Agrios, 1978). There is no report of visible symptoms of leaf injury from nitric oxide (Taylor and MacLean, 1970). Acute foliar markings produced by high concentration of NO_2 exposure are characterised by water-soaked lesions, which first appear on the upper leaf surface followed by rapid tissue collapse. The lesions with time extend throughout the leaf and produce small irregular nectrotic patches. The nectrotic patches are usually white to tan or brown but sometime bronze in colour. The interveinal lesions are prominent at the apex and along with margins, but may occur on the leaf surface (Benedict and Breen, 1955; Middleton et al., 1958; Taylor and Eaton, 1966, MacLean et al., 1968). In chesseweed, Kentucky bluegrass and mustard, NO_2 exposure

resulted in a polished, dark waxy coating on the leaf surface which persisted for about 1 week after exposure while in sugarbeet, NO_2 developed grey glazed appearance on the leaves (Czech and Nothdurft, 1952; Benedict and Breen, 1955). MacLean et al. (1968) observed that besides the foliar symptoms, high concentration of NO_2 causes abscission of leaves and fruits of citrus and defoliation of azalea and hibiscus. NO_2 uptake is decreased with the increase in soil salinity which is associated with reduced stomatal conductance. Such impact of NO_2 treatment of beans was observed by Fuhrer and Erismann (1980).

Although the NO_2 concentration and duration of exposure are both important factors to be considered in determining the expected severity of injury to plants in the case of high concentration exposures, there is no direct relationship between time and concentration, except within very narrow ranges. The concentration of NO_2 influences the extent of injury more than the duration of exposure (MacLean et al., 1968). In the ambient condition, NO_2 affects plant growth even at the concentrations less than 1 ppm (Taylor and Eaton, 1966).

GASEOUS AIR POLLUTANTS (SECONDARY TYPE)

Ozone (O_3)

Ozone is the most important plant pathogenic component of photochemical oxidant air pollution. Exhausts of automo-

biles and other internal combustion engines are probably the most important sources of ozone and other phytotoxic pollutants. Incompletely burned hydrocarbons and NO_2 are released into the atmosphere by the automobile exhaust. In the presence of UV light, this NO_2 reacts with oxygen and forms O_3 and NO. The ozone may react with NO to form the original compound. But in the presence of unburned hydrocarbons NO reacts with hydrocarbons instead of ozone and therefore, O_3 is released in the atmosphere (Agrios, 1978). The naturally produced O_3 concentration at ground level is generally less than 0.03 ppm.

Ozone enters through stomata in leaves, where it accumulates in the palisade layer ultimately causing bleaching or discolouration and collapse of the palisade cells. O_3 affects primarily expanding leaves, but not very young or old, mature leaves. O_3 causes tippling, mottling and chlorosis of the leaf, usually on the upper leaf surface. The colour of the affected leaves varies from light tan to red or almost black, depending upon the plant. Affected leaves of some plants such as citrus, grapes and pines drop prematurely (Darley and Middleton, 1966; Agrios, 1978). Plant response to O_3 is, however, dependent on various environmental factors (Heck, 1968; Ting and Dugger, 1968).

The most common symptom on many deciduous trees, shurbs and some herbaceous plants is localized thickening

and pigmentation of the cell walls resulting in sharply defined small dot-like coloured lesions (Ledbetter et al., 1959). Generally the interveinal region is injured, so lesions are usually angular in shape. The veins are usually not affected except in plants where pigment formation takes place. Pigment formation can produce an overall colouration of the upper leaf surface when the lesions are dense (Heck et al., 1970). Small unpigmented necrotic spots or more general upper surface bleaching is a common type of injury on most of herbaceous and many woody plants (Ledbetter et al., 1959). When the injury becomes more severe then upper epidermal cells collapse and become colourless. A shiny oily or waxy appearance of the upper leaf develops in some plants during O_3 exposure. These symptoms disappear after the termination of the exposure. A water-soaked appearance often develops followed by drying and bleaching which results in typical bifacial necrosis within one or two days (Heck et al., 1970). Epidermal cells remain uninjured while the palisade cells and spongy mesophyll become injured. Many injured cells remain alive but chloroplast is disrupted and the chlorophyll amount is reduced significantly (Hill et al., 1961). Chlorotic mottling or chlorotic flecks are common symptoms on pine. Alfalfa develop large light green chlorotic areas with many irregular islands of normal green tissue dispersed in them. In some plants the tissue eventually becomes uniformly chlorotic and leaves may drop prematurely (Ledbetter et al., 1959).

The entrance of O_3 into plant leaves through stomata is well established. It has been observed that resistant bean cultivar have fewer stomata than a sensitive (susceptible) cultivar . During the exposure, stomata on the resistant cultivar showed partial closure, where as those on the sensitive cultivar did not show any closure (Butler and Tibbitts, 1979). Stomatal closure caused by moisture stress or other factors can protect even the sensitive species from injury (Macdowall, 1965). There are some evidences that O_3 itself may induce stomatal closure, thus reducing the amount of O_3 entering the leaf and contributing to the resistance to O_3 injury in some plants (Engle and Gabelman, 1966). Stomatal closure was more important than stomatal number in determining sensitivity. Bean plant showed stomatal closure even at low concentration (Heck et al., 1986). However, no relationship was found between O_3 sensitivity and the number of stomata or the rate of gas exchange in azalea, sweet corn, soybean and tobacco (Gesalman and Davis, 1978; Harris and Heath, 1981; Heck et al., 1986). In the controlled exposure conditions, the impact of O_3 on the several physiological activities like photosynthesis, respiration, transpiration and the accumalation of starch, sugar, mineral etc. has been studied by several workers on different crop plants (Blum et al., 1982; Hill and Littlefield, 1969; Jensen, 1981; Macdowall, 1965; Pell and Brennan, 1973; Todd, 1958; Todd and Probst, 1963).

Ozone is reported to cause various types of damages

in a number of crops like tomato, potato, cotton, pepper, sunflower, soybean, snapbean, clover etc. 0.04-0.10 ppm concentration of O_3 for 8 h is sufficient to produce visible foliar injury in sensitive plants while 0.08-0.20 ppm O_3 for 8 h would be required to produce injuries in resistant plants (Heagle, 1973). Ozone in ambient conditions has been found to cause reduction in the tomato yield and was responsible for 85% of reduced fruit size along the gradient at the 0.10 ppm concentration for 20 h, 50% reduction in yield has been recorded (Oshima et al., 1977a, 1977b). In the controlled exposure studies on several crop plants like tomato, potato, pepper, carrot, cotton, soybean, snap-beans, clover, fescue etc., the impact of different concentrations of O_3 has been determined by various workers (Bennett et al., 1979 Bennett and Oshima, 1976; Blum and Heck, 1980; Blum et al., 1983a, 1983b; Clarke et al. 1983; Grunwald and Endress, 1984; Henderson and Reinert, 1979; Letchworth and Blum, 1977; Manning and Feder, 1976; Oshima et al., 1979; Pell et al., 1980; Shimizu et al., 1981).

Particulate air pollutants

A major part of air pollutants are particulate matters. The major particulate air pollutants are coal dust, flyash, lime dust, cement dust, soil dust particles, etc. Important sources of particulates are production of coal and cement; combustion of coal, gasoline and fuel oil, lime kiln operations, incineration and soil erosion, agricultural burning

and wrong agricultural practices, volcanic erruptions, transporation and construction etc. According to Das (1986), in the developing countries particulate air pollutants are the major problem, while in the developed countries the problem of particulate air pollutants is not so important. In India, 40-44% air pollutants are of particulate type.

Particulate matters settle on plant parts and cause severe damage to the plants. They cause chlorosis, necrosis, and death of the tissue, when the heavy deposition of the particles occurs. Many particles are byproducts of agricultural practices and are usually inert (Darley and Middleton, 1966; Heck et al., 1970). Cement dust, alkaline in nature produces injury to plants in the close vicinity (Darley, 1966). In a closed chamber study, wheat plants showed reduction in transpiration rate, chlorophyll content and productivity due to cement dust pollution (Singh and Rao, 1981). Lime dust particles form encrustations on leaves of vegetation with a resultant reduction in photosynthesis, vigour and hardiness of the plants. Heck et al., (1970) noticed that high particulate emmission from the different sources caused the reduction in quality of the vegetables and fruits growing close to the source.

Colwill et al., (1979) observed dust deposits on the leaves of the plants grown along the road side with highly busy traffic. Such plants showed poor growth. There have been numerous reports that dust of varying origins

interfere with stomatal functioning mostly by filling and blocking the stomatal aperture (Ricks and Williams, 1974; Fluckiger et al., 1978, 1979), increase leaf temperature (Eller, 1977; Fluckiger et al., 1978) and transpiration (Beasley, 1942; Eveling, 1969), reduce photosynthesis (Darley, 1966), and increase the uptake of gaseous air pollutants (Ricks and Williams, 1974). All these effects eventually result in poor growth of suffering plants.

Acid rain

Some NO_x primary air pollutants (SO_2 and NO_x) are converted into acids after contact with water present in atmosphere and with atmospheric precipitation come down. This is referred to as acid rain. According to Cowling (1982) the phenomenon of rain fall acidification by pollutant emissions was recognized by Hales as early as 1757 in England and its effects were first examined by Robert Angus Smith as early as 1870s. However, modern attention to acid rain began in 1948 (Oden 1968).

Acid rain of pH 3.0-3.6 are reported from Sweden, Norway and eastern United States. The average acidity of rainfall in eastern United States was estimated to be below pH 4.5 in 1972-73. The changes have been attributed to acidic substances formed in the atmosphere, mainly from oxides of sulphur and nitrogen produced during combustion of fossil fuels (Cogbill and Likens, 1974; Likens and Bormann, 1974).

Acid rain causes primarily the acidification and alteration of water and soil. It has been recognized that herbaceous plants are more sensitive to direct injury by acid rain than woody plants (Heck et al., 1986). The most striking effect on vegetation was reported on peatmoss (Sphagnum), an aquatic plant. Lakes were found to be acidified at the bottom upto 18 meter depth in Sweden (Grahn et al., 1974). Direct injury of terrestrial plants by artificial mists of simulated rain containing dilute sulphuric acid, increased leaching of nutrients from pinto bean and sugar maple seedling foliage (wood and Bormann, 1974). In soybean and kidney bean plants when exposed to acid rain of pH 3.2 and pH 6.0 for 17 weeks duration, intermittently in the field condition, no important effects were detected in number of pods formed, in soil acidity or in amounts of essetial elements in the soil or foliage of the plants. No significant difference were observed in fresh weight of shoots, roots or pods both in field and glasshouse (Shriner and Johnston, 1981).

Pollutant Mixture

Pollutant mixture effects to plants were recognized in 1970s. The studies have generally shown increased effects with mixtures of pollutants over effects from individual pollutants. However, the combined effects of air pollutant mixture can be either synergistic, antagonistic or additive. Responses of plants to pollutant mixtures include visible

symptoms of injury, altered growth and development, physiological and metabolic imbalances, and the accumulation of certain elements and metabolites. Decrease in plant growth and yield are often the critical agricultural responses. The most important pollutant mixtures are O_3 + SO_2, SO_2 + NO_2 and O_3 + SO_2 + NO_2. Several other pollutant mixtures like O_3 + NO_2, SO_2 + HF, SO_2 + NaF, NO_2 + HF, O_3 + H_2S and O_3 + acid rain are also known to cause injury in several plants (Reinert, 1984; Heck et al., 1986).

O_3 - SO_2 mixture showed synergistic, antagonistic and additive interaction in the different concentrations on several crop plants (Shew et al., 1982 Ormrod et al., 1983; Shertz et al., 1980; Foster et al., 1983; Heagle and Johnston, 1979; Pratt et al., 1983). But in a study Olszyk and Tibbits (1982) recorded that the foliar injury, reduced leaf area, chlorophyll, leaf weight, did not show any interactive response when garden pea were exposed to 0.06 and 0.27 ppm O_3, 0.11 and 1.72 ppm SO_2 mixture for 2,4 or 8 h.

ROOT NODULE BACTERIA

Root nodule bacteria fix symbiotically the atmospheric nitrogen in association with legumimous plants. The nodule-forming bacteria belong to Rhizobium and Bradyrhizobium of the family Rhizobiaceae. Genus Rhizobium includes fast growing bacteria while the slow growing bacteria are included in Bradyrhizobium. (Jordan, 1982, Huang, 1987). Rhizobium

and Bradyrhizobium are gram negative bacteria, rod-shaped of short to medium size. Usually nodule-forming bacteria live freely in soil and in the root region of both leguminous and non-leguminous plants. However, they can enter into symbiosis only with leguminous plants, by infecting their roots and forming nodules on them. Different species of Rhizobium respond to the different plants. In legume-root-nodule symbiosis, root nodule bacterium is recognized as microsymbiont. When nodule becomes senescent after a period in nitrogen fixation, decay of tissue sets-in liberating motile forms of root nodule bacteria into soil which normally serve as a source of inoculum for the succeeding crop of a given species of legume (SubbaRao, 1972, 1975). Root nodule bacteria penetrate in the root from the root hair through the intercellular spaces and form nodule in the upper cortical regions. The core of a mature nodule constitutes the bacteroid zone surrounded by several layers of corticalcells. The volume of bacteroid zone in effective nodules has a direct positive relationship with the nitrogen fixed. The effective nodules are generally large and pink in colour due to leghaemoglobin (Bergerson and Briggs, 1958).

ROOT-KNOT NEMATODES

Root-knot nematodes (Meloidogyne species), a highly destructive group of plant parasitic nematodes, are world-wide in distribution. They have extensive host range and interact with a large number of fungi, bacteria and viruses.

In the areas where the root-knot nematodes are not managed, average crop yield losses are estimated to be about 25% with damage in individual fields ranging as high as 60% (Sasser, 1980; Sasser and Carter, 1982). Out of more than 70 species of Meloidogyne known at present, 4 species viz., Meloidogyne incognita, Meloidogyne javanica, Meloidogyne arenaria, Meloidogyne hapla are recognized as most common and damaging throughout the world and are called major species of root-knot nematodes (Taylor et al., 1982). These species cause root-knot disease in many different kinds of crops like cereals, vegetables, pulses, fibre-yielding crops, fruit crops, plantation crops, ornamentals etc. (Sasser, 1980; Sasser and Carter, 1982). Root-knot nematodes also interact with other plant pathogenic organisms synergistically causing more loss to the plants. Most frequent interaction of root-knot nematode has been reported with fungi and bacteria (Powell 1971a, 1971b; Taylor, 1979; Khan, 1984; Sikora and Carter, 1987).

INTERACTION OF NODULE-FORMING BACTERIA AND PLANT PARASITIC NEMATODES

Root nodule bacteria are found in the nodules on the root surface of legumes while the plant parasitic nematodes have the different feeding sites depending upon the mode of parasitism. Some nematodes are surface feeder while others are endoparasitic. So, these nematodes interact with

Rhizobium in different patterns. Interactions of Rhizobium spp. with sedentary endoparasites like Heterodera glycines and Meloidogyne spp. have been demonstrated on some crops. It has been observed that soybeans infected with H. glycines usually have few bacterial nodules (Barker et al., 1972; Hussey and Barker, 1976). However, on clover Heterodera trifolii and M javanica were not found to have much effect on nodules. Both nematodes reproduced well in nodules. However, nodules containing M. javanica deteriorated more rapidly than non-infected, reducing the total benefit from the nitrogen-fixing bacteria (Taha and Raski, 1969). The formation of nodules on root-galls and gall formation on the nodules have been reported by Robinson (1961) and Taha and Raski (1969). Ayala (1962) reported parasitism of bacterial nodules by Rotylenchulus reniformis in Cajanus indicus. Nigh (1966) observed the reduction in nodulation of alfalfa by M. javanica. Reduced nodulation due to root-knot nematode infection observed in soybean was because of the possibility that nematodes rendered the infected plant roots physiologically incompatible to the bacteria (Balasubramanian, 1971). Cyst nematodes, Heterodera spp. inhibit nodulation and N-fixation in most of the plants. A drastic reduction of total nitrogen in H. trifolii infected plants caused their stunting. H. trifolii reproduced readily in white clover while the nodule number was altered by root suppression (Taha and Raski, 1969). Different races of H. glycines show different effects on root nodulation and N-fixing capa-

city of soybean. Race 1 was found more effective than race 2 and 4. In race 1, nodulation and N-fixation increased initially but afterward decreased (Lehman et al., 1971). Barker and Huising (1970) also reported the antagonistic interaction between H. glycines and R. japonicum. Barker et al. (1971) found that R. japonicum nodular tissue was unfavourable for cyst development of race 1 of H. glycines. H. glycines also inhibits leghamoglabin content in soybean (Huang and Barker, 1983). Sharma and Sethi (1975) also reported that nematodes interferred with the legheamoglobin content of the cowpea root nodules, with M. incognita causing more reduction than H. cajani. Bopaiah et al. (1976) observed a reduced nodulation and less nitrogen content in mung (Vigna radiata) when M. javanica preceded Rhizobium. Xylary elements in soybean and peanut serve as barrier to the penetration of migratory endoparasite like Pratylenchus penetrans and ectoparasite like Belonolaimus longicaudatus but sometimes these nematodes caused the deterioration of bacteroids present in the nodules of the Wando pea plants lacking xylary elements (Barker and Hussey, 1976).

INTERACTION OF AIR POLLUTANTS AND ROOT NODULE BACTERIA

On this aspect little attention has been given thus far. But in the studies carried out, it has been found that generally all the pollutants have negative effect over the root nodule bacteria. Reinert and Weber (1980) have found that O_3 reduced the number and dry weight of the bacterial

nodules in soybean. Blum and Tingey (1977) have also reported that acute O_3 exposure inhibited bacterial nodules in soybeans. SO_2 and NO_2 alone and in mixture also significantly reduced nodule number but no significant effect was observed on the individual nodule size. This reduction in nodule number resulted in the reduction of N-fixation in soybean (Klarer et al., 1984).

The simulated acid rain of pH 3.2 also inhibited bacterial nodulation in soybeans and kidney beans. The total nodule weight was also reduced, no significant differences were detected in average weight of individual nodules, which indicate that simulated acid rain appeared to have effect on nodule formation than the development of nodules which have once initiated. It is also reported that nodulation was lesser in the plants, when acidified rain treatment was given on foliage only, compared with the plants having rain on both foliage and soil (Shriner and Johnston, 1981). The nodulation in soybeans and kidney beans has also been found to be inhibited by simulated acid rain of pH 3.2 by Waldron (1978). He also found that hydrogen ions causes all these changes in nodulation rather than sulfate ions and suggested it a host mediated effect.

INTERACTION OF AIR POLLUTANTS AND PLANT PARASITIC NEMATODES

The effect of air pollutants on the host-nematode relationships has not yet been studied extensively. But

there are a few reports. Bassus (1968) observed that the saprophagous and predaceous nematode populations were more in the forest areas, severely damaged by SO_2 and alkaline particulated material than the slightly damaged areas. Weber et al., (1979) studied the response of plant parasitic nematodes to O_3 and SO_2, singly and in mixture. Selecting five plant parasitic nematode species with different modes of parasitism, they exposed begonia and soybean plants infected with the nematodes to SO_2 singly or in combination, and to charcoal filtered control air and found different responses of the nematodes to air pollutants. Exposure of infected soybean plants to O_3 and O_3-SO_2 mixture, inhibited reproduction and development of Heterodera glycines (sedentary endoparasite) and Paratrichodorus minor (ectoparasite) but the increase of Belonolaimus longicaudatus was unaffected. Exposure of soybean plants to SO_2 enhanced the reproduction of Pratylenchues penetrans (migratory endoparasite) compared with that in plants exposed to the charcoal filtered control air or O_3. Foliar injury of begonia by O_3 or O_3-SO_2 mixture inhibited Aphelenchoides fragariae (foliar migratory endoparasite). Suppressive effects on A. fragariae were greater in leaves pre-exposed to O_3 or O_3-SO_2 mixture rather than after leaves were inoculated with the nematode.

Shew et al. (1982) studied the response of tomato to possible interactions between O_3 and nematode (Pratylenchus penetrans) inoculations and found that the presence

of P. penetrans attacking the roots enhanced the negative effects of O_3-SO_2 on leaf growth but supressed the inhibitory effects of O_3-SO_2 mixture on axillary shoot growth. In the ambient ozone exposure, 20% more galls developed on tobacco plants inoculated with root-knot nematode, Meloidogyne hapla when compared with plants sprayed with antioxidant. Increase in dry weight of shoot, root and biomass of plants sprayed with antioxidant was also observed. These results indicated that antioxidant indirectly reduced gall development. Thus the tobacco plants infected with M. hapla were found more susceptible to ambient O_3 (Bisessar and Palmer, 1984). Shriner (1978), however, recorded decrease in root infection and reproduction of M. hapla infecting red kidney beans in field conditions, treated three times weekly with simulated acid rain at pH 6.0 or 3.2 .

In a recent study by Bolla and Fitzsimmons (1988), white, Scots and Austrian pine seedlings were treated with simulated acid rain (pH 3.6) and inoculated with specific pathotype of Bursaphelenchus xylophilus. Oleoresin concentration increased slightly and carbohydrate concentration decreased in acid rain treated seedlings. These changes were significant in the white and Scots pine seedlings, when nematode inoculation followed the acid rain treatment. Wilting of seedlings was delayed and nematode reproduction decreased in acid rain treated white pine seedlings inoculated with B. xylophilus. Acid rain treated Austrian pine seedlings were resistant to B. xylophilus, but acid rain treated

Scots pine seedlings lost tolerance to B. xylophilus and wilted 50-60 days after inoculation.

INTERACTION OF AIR POLLUTANTS AND OTHER PLANT PATHOGENS

The interaction of air pollutants with several plant pathogens other than plant parasitic nematodes have been recognised and reviewed by several workers (Bruck and Shafer, 1984; Darley and Middleton, 1966; Heagle, 1973; 1982; Heck et al., 1986; Treshow, 1975). These plant pathogens are fungi, bacteria and viruses.

Interaction of Air Pollutants and Fungal Plant Pathogens

Investigations have been carried out on the interaction of plant parasitic fungi and air pollutants both in ambient and in glasshouse conditions. The major air pollutants known to affect the host parasite relationship of plants infected with fungi are SO_2, O_3, HF and acid rain.

SO_2 usually inhibits the growth and development of plant parasitic fungi in the polluted area (Scheffer and Hedgcock, 1955; Skye, 1968). In some studies, it has been shown that with the increasing distance the effect of SO_2 on disease incidence and development decreases notably (Linzon, 1958). Field observations have indicated that the obligate parasitic fungi are generally more sensitive to SO_2 than non-obligate parasitic fungi. This has been substantiated by the results of glasshouse studies in controlled

conditions (Weinstein et al., 1975). SO_2 was found to inhibit parasitism of wheat by Puccinia graminis, but type of wheat resistance to rust was critical in response depending upon different cultivars (Laurence et al., 1979). Non-obligate parasitic fungi are inhibited, stimulated or do not respond to SO_2 pollution. Exposures to SO_2 decreased parasitism of bean by Uromyces phaseoli but did not affect parasitism of tomato leaves by Alternaria solani (Weinstein et al., 1975). The number of lesions caused by Helminthosporium maydis was found to decrease by 38% when exposed to SO_2 on 8 days before inoculation (0.15 ppm for 14 h/day). If the exposures occurred on the 8 days before and on the 2 days after inoculations the number of lesions decreased by 13-16% only (Laurence et al., 1979).

Weidensaul and Darling (1979) recorded increase in the number of lesions caused by Schirrhia acicola on needles of Scots pine seedling, when exposed to 0.20 ppm for 6 h of SO_2 for 5 days. Fungal growth and spore germination were also affected by SO_2. Within the plant tissues, the fungal hyphae showed resistance to SO_2. The hypha of different fungi showed variations in sensitivity to SO_2 doses (Mc Callen and Weedon, 1940). Botrytis sp. (cinerea type) in pure culture was resistant to 4.0 ppm concentration of SO_2 for 11 h, while S. acicola grew normally and produced viable conidia after exposure to 1.0 ppm SO_2 for 4 h (Ham, 1971). Saunders (1966) found that Aspergillus niger, Alternaria

brassicicola and Didymellina macrospora were unaffected in nutrient solution containing 90 ppm equivalent SO_2 while Penicillium was slightly stimulated in growth. The spores of most of fungi show great resistance to direct expoure to SO_2, even at the high doses (Couey and Uota, 1961; Hibben, 1966). Spore germination was inhibited more with increasing water content, in most of the fungi (Couey, 1965; Couey and Uota, 1961). Sharp (1967), however, reported that uredospores of Puccinia striiformis showed no resistance to SO_2 exposure.

O_3 inhibits obligate fungus parasitism, whereas facultative parasitism might be increased, inhibited or not affected. O_3 affects rust indirectly while powdery mildews seemed to be affected directly at the time of conidial formation, conidial germination and penetration. The mature spores showed resistance to ambient O_3 pollution (Heagle, 1973). Uromyces phaseoli, an obligate parasite on bean, has been reported to have both negative and positive response for O_3 in the controlled conditions (Resh and Runeckles, 1973). Microsphaera alni was found to be very resistant by Hibben and Taylor (1975) when exposed to 1.0 or 0.25 ppm of O_3 for 6 and 72 h respectively. However, the powdery mildew of barley, Erysiphe graminis has been observed to be sensitive to O_3 during conidial development, germination and penetration (Heagle, 1973). Botrytis squamosa, a facultative fungus, developed two times more lesions on the onion plants, exposed to O_3 (Wukash and Hofstra, 1976, 1977). The response

of O_3 to Helminthosporium maydis on maize leaves depends on the time of exposure in relation to the stage of fungus development as well as the concentration of O_3(Heagle, 1977). James et al., (1980) claimed that Heterobasidion annosum can cause the death of pine tree injured by O_3. Puccinia coronata, crown rust of oat was slightly injured by O_3 and the uredia were significantly smaller in size, when exposed to 0.10 ppm O_3 for 6 h 10 days after inoculation (Heagle, 1970). The small doses of O_3 was found to be inhibitory for sporulation of wheat stem rust, Puccinia graminis. This decrease in sporulation was due to injury of host mesophyll cells and decreased hyphal growth (Heagle and Key, 1973).

Fungus colonies on culture media are not much affected by exposure to large doses of O_3 although small doses can inhibit the colony growth, suppress development of aerial hyphae and decrease sporulation (Ingram and Haines, 1949; Hibben and Stotzky, 1969). In most of the fungi, the dry spores are more resistant to O_3 than wet spores (Hibben and stotzky, 1969).

Acid rain has been also recognised to affect the host-parasite relationship of several fungi. Simulated acid rain caused inhibition of Cronartium fusiforme on the willow oak inoculated with aeciospores. The number of infections and telia were decreased when rain acidified to pH 3.2 with H_2SO_4 acid was applied on each of 14 days before and after

inoculation (Heagle, 1982). The number of Helminthosporium maydis lesions on maize increased when conidia were incubated in water at pH 3.5 before inoculation and the leaves were subsequently treated with rain at pH 3.5 (Shriner, 1978).

In a survey of fungi in the cement dust polluted area, Rai and Pathak (1981) found that total number of fungi associated with potato leaves were more in polluted area which indicated that cement dust was not inhibitory to fungi. The maximum number of Penicillium javanicum isolates was found in cement dust polluted areas while Alternaria solani was less.

Interaction of air Pollutants and Plant Pathogenic Bacteria

The effects of different air pollutants on plant pathogenic bacteria have been recognized (Heagle, 1973, 1982; Laurence and Aluisio, 1981; Heck et al., 1986). SO_2 exposure is reported to reduce the rate of lesion development and lesion size on plants suffering with bacterial diseases. Exposure time and dosage of pollutants have been observed to be limiting factors (Laurence and Aluisio, 1981). Corynebacterium nebraskense was inhibited when maize plants were exposed continuously to SO_2 on 5 days bfore inoculation or 2 days after inoculation or in both. The inhibition was, however, maximum in the 2 days post-inoculation exposure. Similarly inhibition of Xanthomonas paseoli was found on soybean with exposure to SO_2. It was highest in both 5 days

pre- or post-inoculation exposures (Laurence and Aluisio, 1981).

Ozone is also known to inhibit the bacterial plant diseases, especially the bacteria causing foliar lesions. Pseudomonas glycinea infecting soybean leaves, when exposed to O_3 (0.08 or 0.25 ppm for 4 h) from 16 days to 1 h before inoculation or from 1 h to 1 day after inoculation, showed the decrease in number of lesions (Laurence and Wood, 1978a). Number of lesions on wild strawberry infected with Xanthomonas fragariae was decreased by O_3 (0.20 ppm for 4 h) (Laurence and Wood, 1978b). Simulated acid rain at pH 3.2 (0.63 cm over 10 minutes per day for 10 days) before inoculation is reported to increase the disease symptoms caused by P. phaseolicola on kidney bean. However, the symptoms were inhibited when the pH 3.2 rain treatments occurred on the 11 days after inoculation (Shriner, 1978).

Interaction of Air Pollutants with Plant Viruses

There have been few attempts to study the response of virus and virus infected plants to air pollutants. There are reports that SO_2 can increase viruses in plants of bean and maize irrespective of the duration of exposure. Southern bean mosaic virus and sulphur content in bean leaves were increased by continous SO_2 (0.10 ppm for 7 days) exposure either before, after or both before and after inoculation. Increase in the severity of infection and symptoms, without

an increase in sulphur content, was observed for maize dwarf mosaic virus (MDMV) in plants exposed to SO_2 continously before or after inoculation (Laurence et al., 1981).

Some workers have investigated the response of viruses to O_3 exposure. Davis and Smith (1974b) observed that pinto bean leaves were partly protected from O_3 (0.25 ppm for 4 h) when inoculated with bean common mosaic virus, 4,5 or 6 days before exposure. The effect did not occur if plants were inoculated 3 days before exposure. Some viruses viz., tobacco ring spot, tomato ring spot, alfalfa mosaic and tobacco mosaic viruses also protected primary leaves of pinto beans from O_3, when inoculated 5 days before exposure (Davis and Smith, 1974a). There are also other reports which show that different viruses protected primary leaves of soybean, pinto bean etc. from injury caused by O_3 (Davis and Smith 1974a; Vargo et al., 1978). In field, tobacco infected with TMV exhibited 60% less injury from ambient O_3 (Bisessar and Temple, 1977). However, tobacco streak virus caused significantly more injury in tobacco exposed to 0.30 ppm of O_3 for 3 h on 1 or 2 days at 3 weeks after inoculation (Reinert and Gooding,, 1978).

The mechanisms for virus induced changes in plants response to O_3 are unknown. Decreased stomatal conductance has been suggested as the mechanism for protection, but this was not proved in some plants. Virus titre, plant age and season have been recognized as important factors (Brennan

1975; Vargo et al., 1978).

INTERACTIONS BETWEEN AIR POLLUTANTS, ROOT NODULE BACTERIA AND PLANT PARASITIC NEMATODES

The interaction between air pollutants, root nodule bacteria and plant parasitic nematodes has not gained much study. Weber et al. (1979) studied such interactions in a leguminous crop and recognized effects of interactions. During the study seven-day-old soybean seedlings were inoculated with Rhizobium japonicum and later after 15 days from sowing, the transplanted soybean plants were inoculated with four plant parasitic nematodes, i.e. Heterodera glycines, Belonolaimus longicaudatus, Paratrichodorus minor and Pratylenchus penetrans and exposed to SO_2,O_3 and O_3-SO_2 mixture. The effects of pollutant-nematode combinations on nodulation varied. Because of the severe inhibition of nodulation of soybean by H. glycines, the number of nodules from roots parasitized by this nematode did not differ among the pollutant treatments. In contrast, nodulation in plants parasitized by B. longicaudatus and P. minor was inhibited by exposure of soybean to O_3 and O_3-SO_2 mixture as compared to the control and SO_2 treated plants while P. penetrans and O_3-SO_2 mixture did not show any remarkable effect on nodulation. In this study O_3 and O_3-SO_2 mixture inhibited the growth of soybean both in the presence and absence of nematode and caused the injuries in leaves. SO_2 inhibited the growth of soybean inoculated with P.penetrans but did not

affect the penetration of H. glycines in soybean roots but inhibited the reproduction and development of H. glycines and P. minor while development of B. longicaudatus was unaffected. Exposure of soybean plant to SO_2 enhanced the reproduction of P. penetrans compared with that in plants exposed to charcoal filtered air or to O_3. O_3-SO_2 mixture also showed similar effects but not much significantly different from the control.

Air pollution effects on crop plants and plant diseases are new and developing areas of research and informations available are still meager. But whatever has been done on the above aspects, gives indication of air pollution damage to crops. Similarly, plant pathogens affecting crop plants are directly or indirectly affected, though informations on this aspect are rather negligible. Air pollutants affecting leguminous crops may imbalance their symbiotic relationship, the nitrogen transformation system, so beneficial for nitrogen economy of legume cultivations. Some studies as summarized above show the possibility of imbalances in this system. This needs to be further and thoroughly investigated and substantiated by more experimental data. Root-knot nematodes also impair nitrogen fixing capability of the system. At the same time, air pollution may stress the host-parasite relationships of root-knot nematodes. This has yet attracted very little attention of investigators. The impact of air pollution on this system and possibility

of synergistic or antagonistic relationship that may develop between various kinds of air pollutants and root-knot nematodes on crop plants are very little known and need to be substantially investigated. It may gradually add a new dimension to the field of Plant Nematology.

SECTION I

IMPACT OF AMBIENT AIR POLLUTION ON ROOT-KNOT DISEASE AND ROOT NODULATION ON CHICK-PEA AND LENTIL IN THE VICINITY OF THE THERMAL POWER PLANT, KASIMPUR

In the beginning of the study, the impact of ambient air pollution on root-knot disease and root nodulation on chick-pea and lentil was assessed by surveying the crop fields in the cropping season (November - March) in the vicinity of the Thermal Power Plant, Kasimpur. The thermal power plant annually consumes about 1,165,007 MT of coal and causes ambient air pollution depending upon the wind characteristics. During the surveys, samples of chick-pea (gram), Cicer arietinum L. and lentil, Lens culinaris Medic. were collected and processed in the laboratory for determining root-knot disease incidence, root galling and eggmass production, root nodulation, and for identification of species of root-knot nematodes and air pollution symptoms. The meteorological data of the area were also obtained from the Meteorological Department, Government of India.

For comparative assessment an area, about 15 km away from the Thermal Power Plant, Kasimpur, in south-west direction, was assumed as unpolluted area.

MATERIALS AND METHODS

Meteorological data

The meteorogical data of the area where the Thermal Power Plant, Kasimpur is situated, in relation to wind speed, temperature, relative humidity and rainfall were collected from the Meteorological Department (Government of India), Aligarh.

Survey and Collection

Surveys of chick-pea (Cicer arietinum L.) and lentil (Lens culinaris Medic.) fields were conducted in the polluted area around the Thermal Power Plant, Kasimpur and the unpolluted area to assess the incidence of root-knot disease, extent of root galling and eggmass production, root nodulation and air pollution symptoms during the cropping season (November - March) in 1986-1987. During the surveys, root samples of chick-pea and lentil from crop fields (10 samples/field) were collected and packed in polythene bags with adequate labellings. The samples were brought to laboratory for examination.

Air pollution symptoms

The leaves of the plant samples collected during the surveys were invariably examined closely for detecting symptoms known to be caused by various air pollutants on plants. The symptoms where present were charactrerized and

matched with the symptoms given in 'Recognition of Air Pollution Injury to Vegetation : A Pictorial Atlas' (Eds. J.S. Jacobson and A.C. Hill). Air pollution Control Association Pittsburg, Pennsylvania, 1970.

Root nodule bacteria

The roots of the field samples collected during the surveys were washed clean and thoroughly examined for the presence of root nodules. The number of functional and non-functional root nodules and nodules infected with root-knot nematodes in the field samples were counted with the help of binocular microscope. The pinkish healthy nodules were taken as functional and others as non-functional. The counts from the polluted area were compared with the samples collected from the unpolluted area.

Root-knot nematodes

The washed roots of each field sample were throughly examined for the presence of galls and eggmasses of the root-knot nematodes. The number of galls and eggmasses per root system were counted. The incidence of the disease was determined by the frequency of occurrence of the disease in the root samples. The frequency of occurrence of the root-knot disease on each pulse crop in each locality was calculated as follows :

$$\text{Frequency of occurrenc(\%)} = \frac{\text{Number of root samples of a crop with infection in the locality}}{\text{Number of root samples of the crop collected from the locality}} \times 100$$

Identification of species

Root samples collected during the surveys were processed for identification of the species of the root-knot nematodes. The characteristics of perineal patterns of females were employed for preliminary identification of species present in the field samples (Eisenback et al., 1981). Thenafter, maintaining the root-knot nematodes present in the field samples in greenhouse on tomato (cv. Pusa Ruby) or eggplant (cv. Pusa Kranti) in separate pots and raising pure populations, North Carolina differential host tests were conducted to confirm the identity of the species (Taylor Sasser, 1978).

Perineal pattern method

To identify the species of Meloidogyne in the field samples, mature females were dissected out from large galls on the roots. Ten to twenty perineal patterns were prepared from each field sample and were viewed under the microscope to study their characteristics. Species were identified on the basis of the characteristics of the perineal patterns (Eisenback et al., 1981).

Differential host test

North Carolina differential host tests (Taylor and Sasser, 1978) were carried out to confirm the identity of the species of Meloidogyne identified by perineal pattern

method. Seedlings of tomato cv. Rutgers, tobacco cv. NC95, pepper cv. California wonder, peanut cv. Florrunner, watermelon cv. Charleston grey and cotton cv. Deltapine 16 were grown in clay pots having sterilized soil in triplicate. Two additional replicates of tomato were included to determine the time of termination of the test.

After determining the number of freshly hatched juveniles (J_2) per ml, plants were inoculated with 5,000 J_2/pot. Juveniles were added to a depression made in the soil at the time of transplanting. Inoculated pots were kept at greenhouse benches. Fifty to sixty days after inoculation, roots were harvested and thoroughly washed with tap water and examined for the presence of galls. Roots with very light infection were stained with Phloxine B to determine the number of eggmasses. Galls and eggmasses were counted and gall index (GI) and eggmass index (EMI) were rated on 0-5 scale. After the rating of root system, results were compared with the differential host test reaction chart to identity the species (Taylor and Sasser, 1978).

OBSERVATIONS

Meteorological data

The location and layout map of the area where the Thermal Power Plant, Kasimpur is situated are given in Figs. 1 and 2. The meteorological data obtained are reported in Figs. 3,4,5 and 6. During the period 1986-87, for which the data are reported, the lowest minimum temperature during

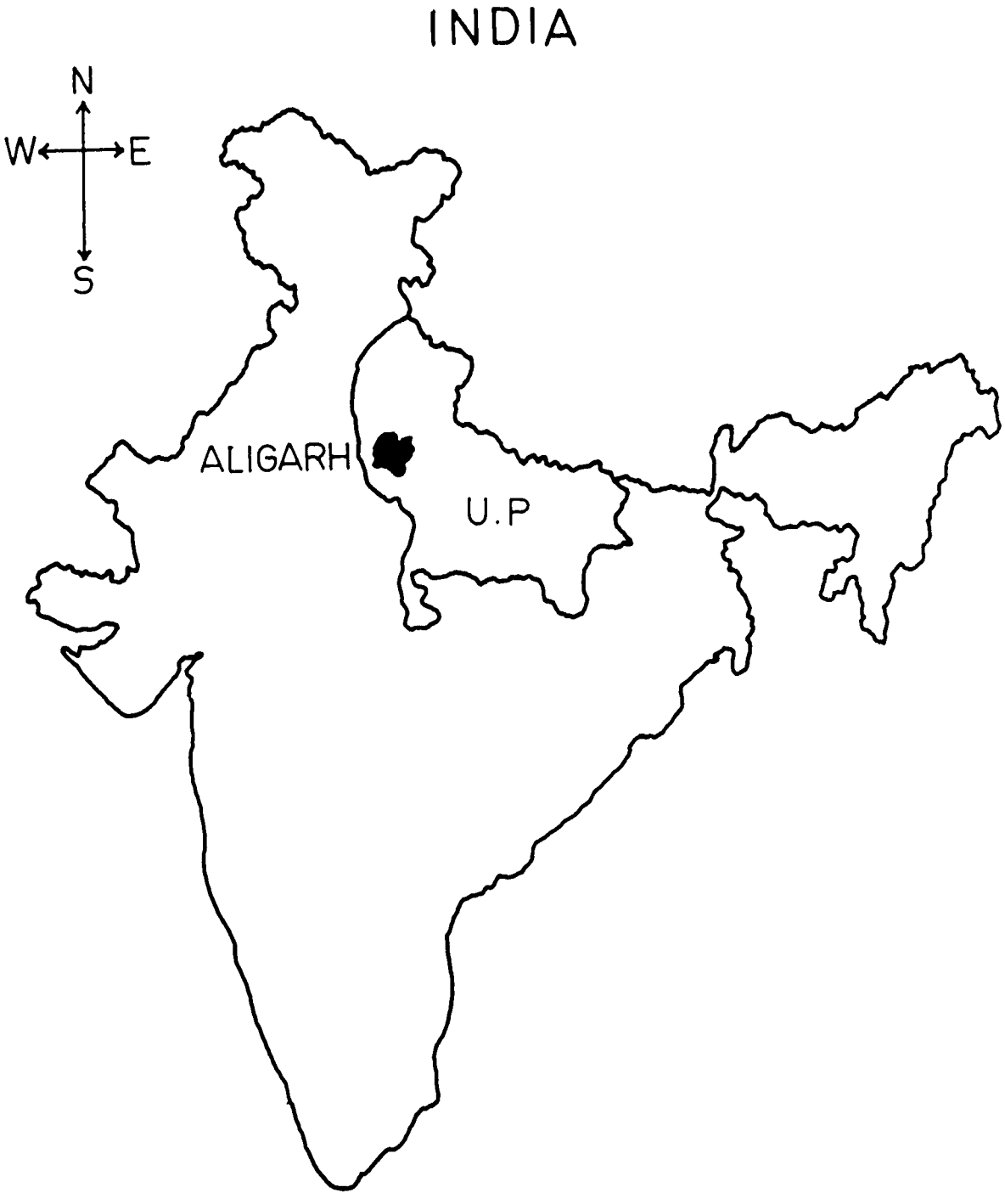

Fig. 1

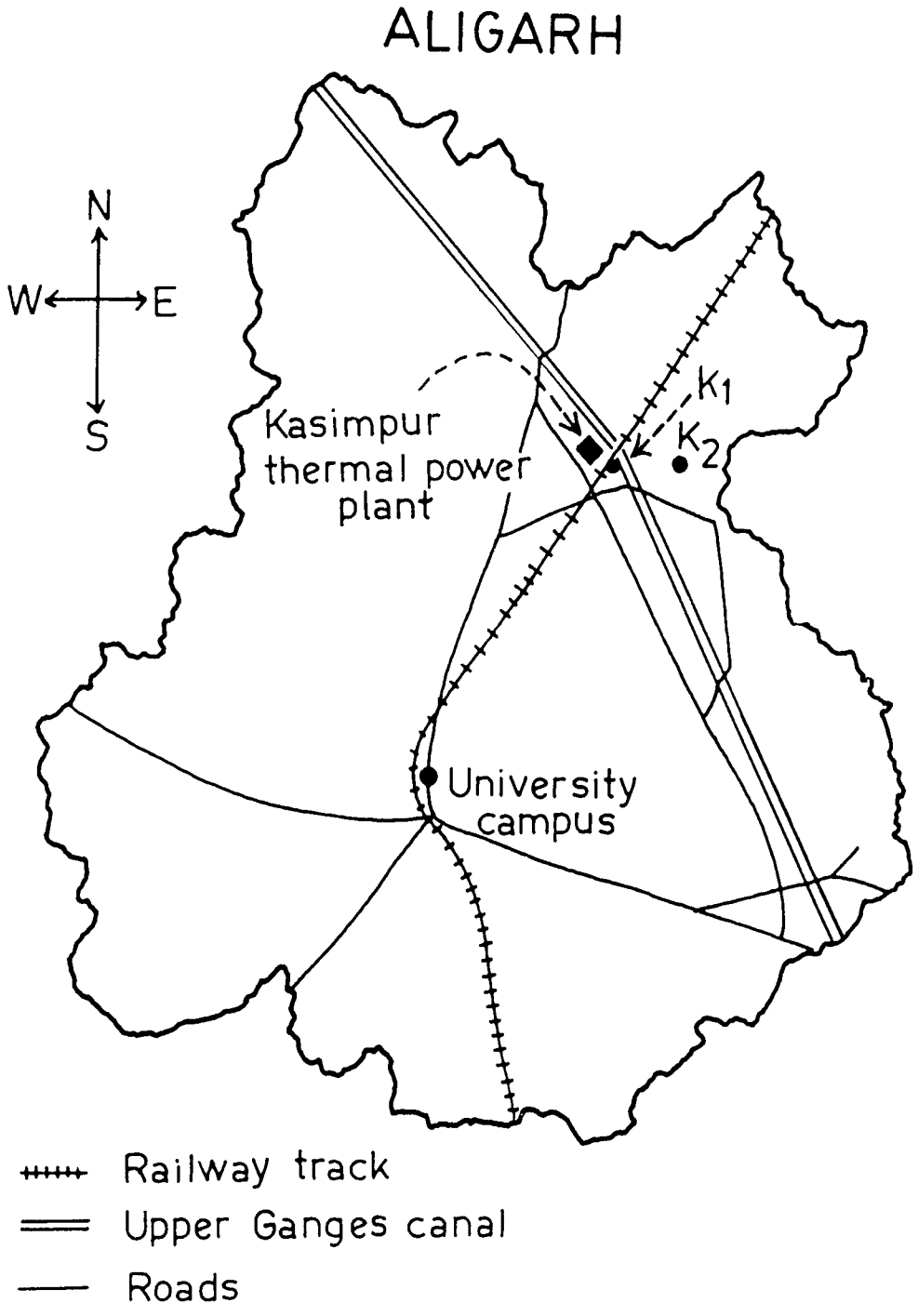
ALIGARH
N
W
E
S
Kasimpur
thermal power
plant
K1
K2
University
campus
Railway track
Upper Ganges canal
Roads

Fig. 2.

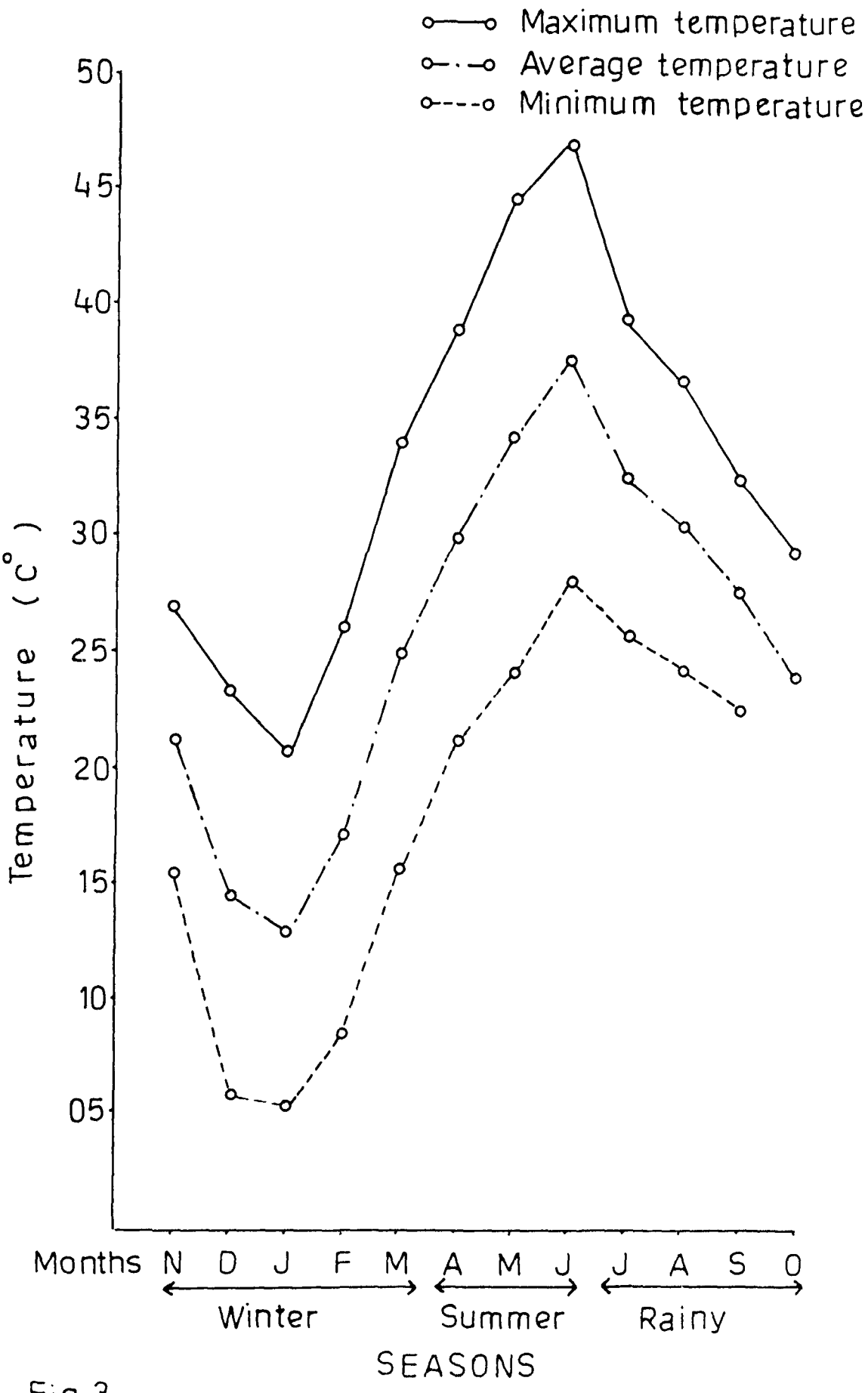
Maximum temperature
Average temperature
Minimum temperature
50
45
40
35
30
25
20
15
10
05
Temperature (C°)
Months N D J F M A M J J A S O
Winter
Summer
Rainy
SEASONS

Fig.3.

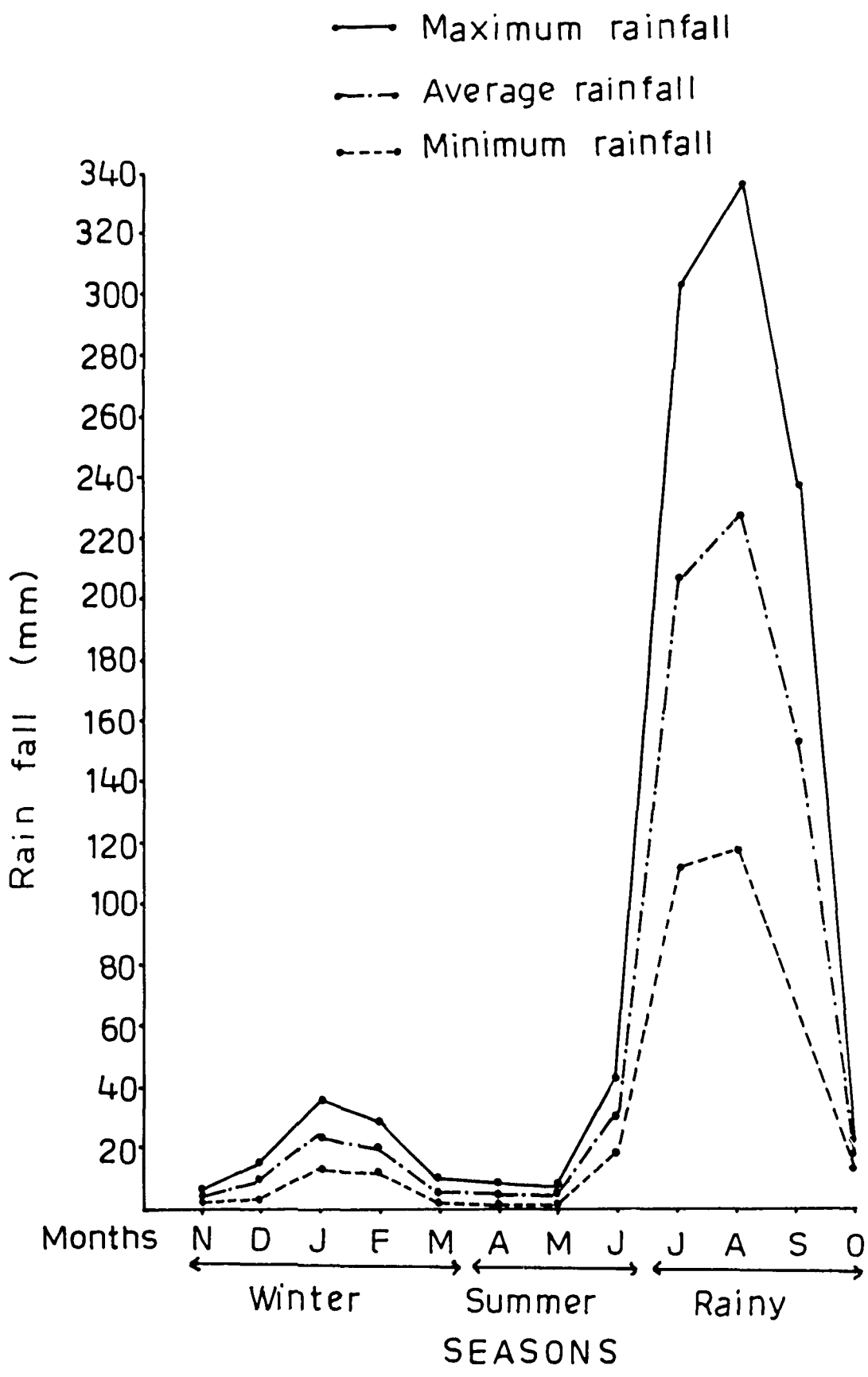

Fig.4. Rainfall (Average of four years)

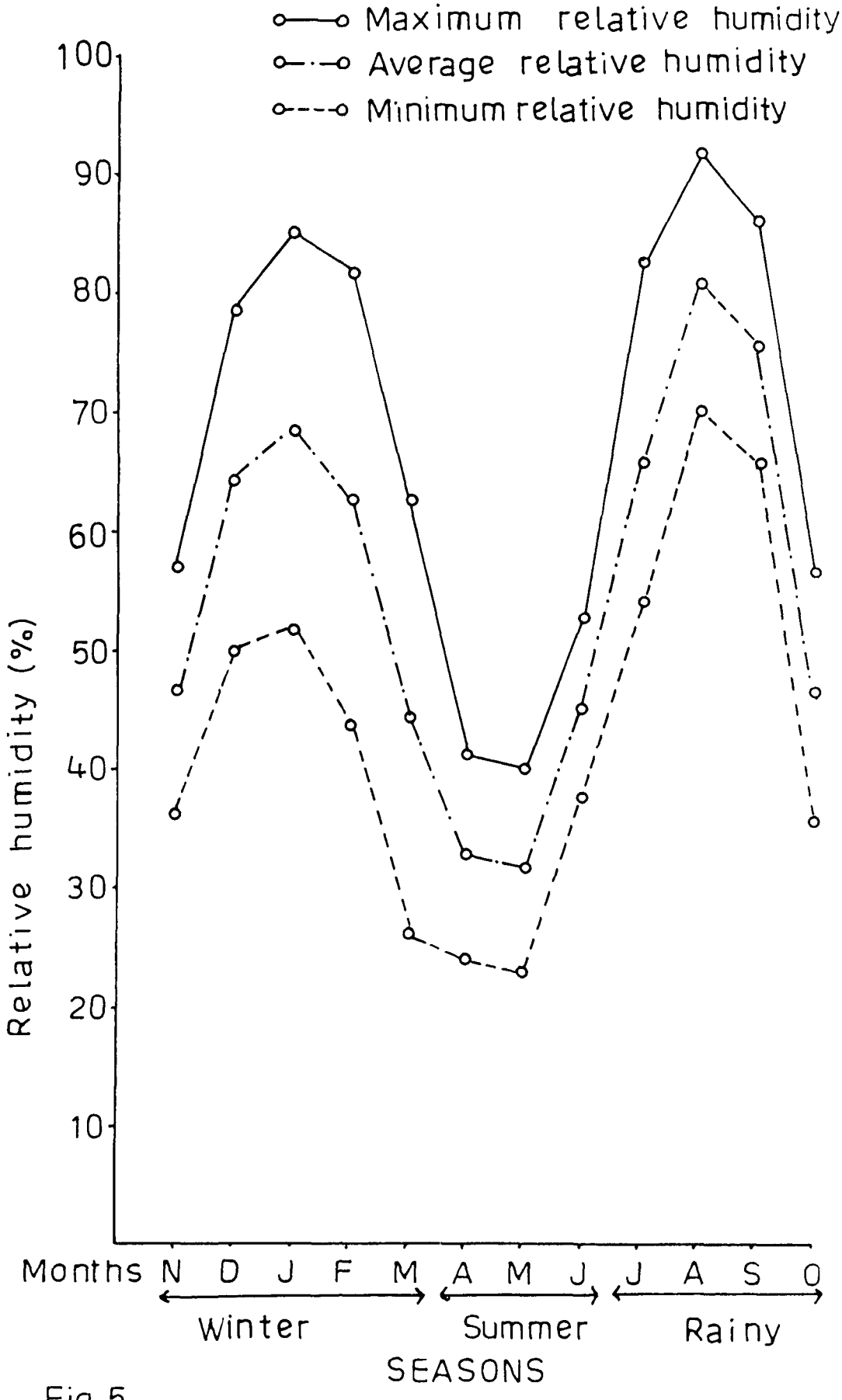
Maximum relative humidity
Average relative humidity
Minimum relative humidity
100
90
80
70
60
50
40
30
20
10
Relative humidity (%)
Months N D J F M A M J J A S O
Winter
Summer
Rainy
SEASONS

Fig. 5.

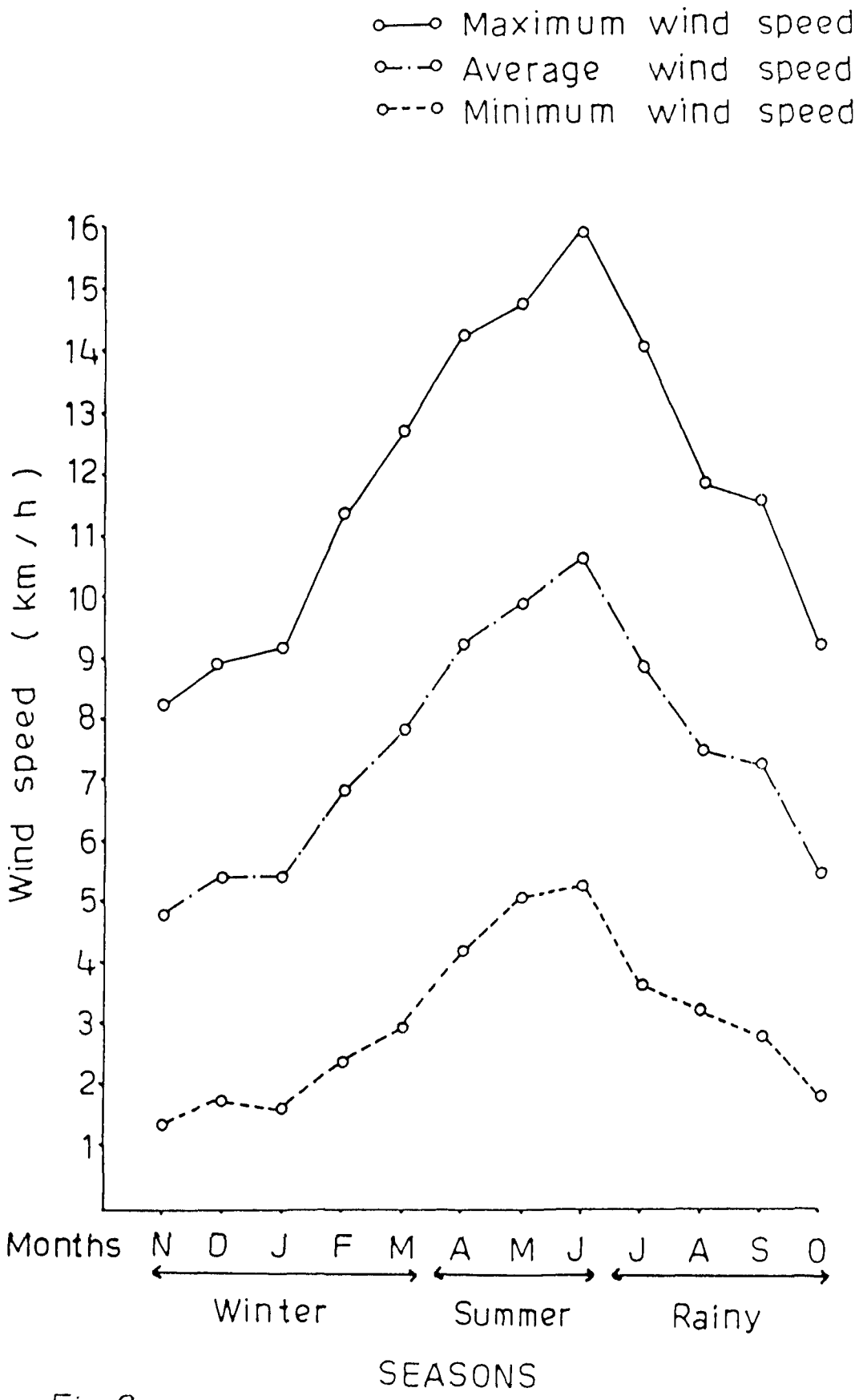
Maximum wind speed
Average wind speed
Minimum wind speed
Wind speed (km / h)
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
Months N D J F M A M J J A S O
Winter
Summer
Rainy
SEASONS

Fig. 6.

winter was 5.32° C. The highest temperature during the summer season was 46.86 C (Fig. 3). The rainfall was lowest in the summer (April - June) and highest during rainy season (July - October). Highest rainfall (387 mm) was in July. During winter the highest rainfall was 36 mm (Fig. 4). The realtive humidity was high during winter (25.88% - 85.29%) and rainy season (35.56% - 91.76%) and low during summer (Fig. 5). The wind speed was highest in summer and lowest in winter season, specially in November. The wind speed gradually increased from November upto June and then declined (Fig. 6).

Air pollution symptoms

Chlorosis of leaves and necrosis of leaf margins were the symptoms observed on chick-pea and lentil, induced by the ambient air pollution caused by the Thermal Power Plant, Kasimpur. Presence or absence of the symptoms, however, varied with the distance from the pollution source and direction. Chlorosis of leaves and necrosis of their margins in both chick-pea and lentil at 1/2 km distance were observed in all the directions. In E, SW, W and NE at 1 km such symptoms on leaves of both crops were also observed. At 1 km, distance in S and N directions, leaves of chick-pea did not show any symptom attributable to air pollution. Lentil leaves showed chlorosis in S but not in N direction. At 2 km distance, in E, W and NE directions, leaves of both the crops exhibited chlorosis. In E direction only necrosis

of leaf margins was shown by lentil leaves. At 4 km distance leaves of both the crops did not show any detectable symptom attributable to ambient air pollution (Table 1 and 2).

Root nodulation

The observations on root nodulation (number of nodules/root system) on chick-pea and lentil grown around the Thermal Power Plant, Kasimpur are summarized in Table 1 and 2. In general, inhibition of root nodulation on both the crops was observed at different distances and directions from the pollution source. At 1/2 km distance, root nodulation and percentage of functional nodules on both chick-pea and lentil were highest in N and were lowest in E direction. The percentage of functional nodules was greater on lentil than chick-pea. In SW direction at 1/2 km, the number of nodules infected with root-knot nematodes was also greater on lentil than chick-pea. In general, the total number of nodules and the percentage of functional and infected nodules were greater in unpolluted area than 1/2 km distance from pollution source. At 1 km distance, in all the directions, nodulation in general was inhibited on both the crops but the total nodules and functional nodules were greater in number than 1/2 km distance in the respective directions. On chick-pea the percentage of infected nodules were greater in SW than N direction. At 2 km distance, root nodulation was also inhibited in all the directions on both the crops but the inhibition was less in comparison to 1 km distance

Table 1. Observations made during the survey of chick-pea fields around the Thermal Power Plant, Asimour, the pollution source and in unpolluted area.

Distance from pollution source	Direction from pollution source	Incidence	Root galling/Eggmass production		Species	Nodule/plant					Air pollution symptom
		Frequency %	Galls/ plant	Eggmasses/ plant		Total	Functional		Infected with nematodes		
							Number	%	Number	%	
Unpolluted	(Control)	67	128	110	MI,MJ	106	88	83.02	14	13.21	
1/2	E	-	-	-	-	19	14	73.68			Chlorosis and necrosis of leaf margins
1/2	S	-	-	-	-	46	36	78.26			Chlorosis and necrosis of leaf margins
1/2	SW	25	37	22	MI,MJ	38	29	76.32	3	7.89	Chlorosis and necrosis of leaf margins
1/2	W	-	-	-	-	21	16	76.19			Chlorosis and necrosis of leaf margins
1/2	N	-	-	-	-	58	46	79.31			Chlorosis and necrosis of leaf margins
1/2	NE	-	-	-	-	24	18	79.16			Chlorosis and necrosis of leaf margins
1	E	-	-	-	-	32	24	75.00			Chlorosis and necrosis of leaf margins
1	S	-	-	-	-	89	73	82.02			—
1	SW	52	68	53	MI,MJ	64	51	79.69	6	9.38	Chlorosis and necrosis of leaf margins
1	W	-	-	-	-	39	30	76.92			Chlorosis and necrosis of leaf margins
1	N	-	-	-	-	64	78	82.98			—
1	NE	16	26	17	MI,MJ	45	35	77.78	3	6.67	Chlorosis and necrosis of leaf margins
2	E	38	61	49	MI,MJ	64	49	76.56	5	7.81	Chlorosis of leaves
2	W	45	68	56	MI,MJ	69	54	78.26	6	10.14	Chlorosis of leaves
2	NE	50	80	69	MI,MJ	71	56	78.87	10	14.08	Chlorosis of leaves
2	E	68	135	112	MI,MJ	98	79	80.61	17	17.34	—

E = East, S = South, SW = South-west, W = West, N = North, NE = North-east

MI = Meloidogyne incognita, MJ = M. javanica.

Table 2. Observations made during the survey of lentil fields around the Thermal Power Plant, Kasimpur, the pollution source and in unpolluted area.

Distance from pollution source	Direction from pollution source	Incidence	Root galling/Eggmass production		Species	Nodule/plant					Air pollution symptom
		Frequency %	Galls/ plant	Eggmasses/ plant		Total	Functional		Infected with nematodes		
							Number	%	Number	%	
Unpolluted	(Control)	52	85	76	MI,MJ	124	107	86.29	17	13.71	
1/2	E	-	-	-	-	23	17	73.91	-	-	Chlorosis and necrosis of leaf margins
1/2	S	-	-	-	-	42	35	83.33	-	-	Chlorosis and necrosis of leaf margins
1/2	SW	10	22	10	MI,MJ	36	29	80.56	5	13.89	Chlorosis and necrosis of leaf margins
1/2	W	-	-	-	-	26	20	76.92	-	-	Chlorosis and necrosis of leaf margins
1/2	N	-	-	-	-	59	49	83.05	-	-	Chlorosis and necrosis of leaf margins
1/2	NE	-	-	-	-	28	22	78.57	-	-	Chlorosis and necrosis of leaf margins
1	E	-	-	-	-	47	37	78.72	-	-	Chlorosis and necrosis of leaf margins
1	S	-	-	-	-	83	72	86.74	-	-	Chlorosis of leaves
1	SW	42	55	48	MI,MJ	68	55	80.88	7	10.29	Chlorosis and necrosis of leaf margins
1	W	-	-	-	-	52	42	80.76	-	-	Chlorosis and necrosis of leaf margins
1	N	-	-	-	-	87	74	85.06	-	-	—
1	NE	-	-	-	-	55	44	80.00	-	-	Chlorosis and necrosis of leaf margins
2	E	32	57	42	MI,MJ	78	63	80.77	7	8.97	Chlorosis and necrosis of leaf margins
2	W	35	64	53	MI,MJ	82	67	81.71	9	10.98	Chlorosis of leaves
2	NE	40	73	62	MI,MJ	86	71	82.56	11	12.79	Chlorosis of leaves
4	E	48	123	105	MI,MJ	94	79	84.04	15	15.96	—

E = East, S = South, SW = South-west, W = West, N = North, NE = North-east.

MI = Meloidogyne incognita, MJ = M. javanica.

in their respective directions. The number of nodules and percentage of functional nodules in E, W and NE and of infected nodules in E and W were greater on lentil than chick-pea. The percentage of infected nodules in NE direction was greater on chick-pea than lentil. The percentage of infected nodules on chick-pea at 2 km in NE were greater than unpolluted area. At 4 km distance, inhibition in root nodulation was observed. But the extent of inhibition in comparison to other distances was less. The number of nodules and percentage of functional nodules were greater on lentil than chik-pea except the percentage of infected nodules which was greater on chick-pea than lentil. The number of total nodules and percentage of functional and infected nodules were greater than 2 km, 1 km and 1/2 km distance in E on both chick-pea and lentil.

Root-knot disease

The observations made during surveys on root-knot disease on chick-pea and lentil in different directions at various distances from the pollution source (stack of the Thermal Power Plant, Kasimpur) are reported in Table 1 and 2. Two species of root-knot nematodes, Meloidogyne incognita (Kofoid and White) Chitwood and M. javanica (Treub) Chitwood were found infecting chick-pea and lentil wherever the disease was encountered. The root-knot disease was found only in south-west (SW) direction at 1/2 km distance from the pollution source (stack). The incidence of the disease

and root galling and eggmass production (number of galls/egg-mass per root system) at 1/2 km distance in SW direction was relatively less than in the unpolluted area. In all other directions, east (E), south (S), west (W), north (N) and north-east (NE) at this distance (1/2 km) no infection was detected. The incidence of the disease and root galling and eggmass production were greater on chick-pea than lentil. At 1 km distance, the infection of root-knot nematodes was found in SW and NE direction. In NE, however, only chick-pea was infected. The incidence of the disease and root galling and eggmass production were poor at this distance in comparison to unpolluted area, but were greater than 1/2 km distance. The incidence and root galling and eggmass production on chick-pea were more in SW than NE. At this distance in SW also the disease incidence and root galling and eggmass production were greater on chick-pea than lentil. At 2 km distance, the disease was found in E, W and NE on both the crops. The disease incidence and root galling and eggmass production were less in all the three directions than the unpolluted area. The incidence of the disease and root galling and eggmass production were greatest in NE and lowest in E. The disease was greater on chick-pea than lentil and was lower than unpolluted area. In E direction at 4 km on chick-pea, the disease incidence and root galling and eggmass production were greater than polluted area. On lentil the incidence of the disease was less at 4 km than unpolluted area but root galling and eggmass

production were greater. Even at this distance the disease was greater on chick-pea than lentil.

In general the incidence of the disease and root galling and eggmass production of the nematodes on both the crops gradually increased with the increasing distance from the pollution source.

DISCUSSION

The thermal power plants consuming coal as fuel emit SO_2, NO_x and flyash, which are mainly responsible for ambient air pollution (Wood, 1968; Gupta, 1981). The gaseous and particulate air pollutants cause injuries to plants which exhibit various types of characteristics symptoms mainly on the foliage (Jacobson and Hill, 1970). In the present observations in the vicinity of the Thermal Power Plant, Kasimpur, both chlorosis and marginal necrosis of leaves of chick-pea and lentil were observed at the sites where the pollution level was high but at the sites, where the pollution level was low only chlorosis was detected. The symptoms shown by the crops, therefore, depended upon the pollution level which is influenced by wind speed, wind direction and the distance from the stack (Smith 1968; Thakre and Aggarwal 1985). The observation of more pollution induced symptoms closer to the stack (1/2 km distance) than other sites shows that the appearance and intensity of the symptoms

were related to the level of ambient air pollution. A gradual decrease in the level of ambient air pollution with the increasing distance from the stack of the Thermal Power Plant, Kasimpur was recorded as reported in the section II.

Chick-pea and lentil crops in the vicinity of the Thermal Power Plant, Kasimpur were found infected with root-knot nematodes, M. incognita and M. javanica, that two most commonest species of the area. These species of root-knot nematodes are commonly found infesting crop fields in the area. The incidence of the disease and intensity (root galling and eggmass production) were less in the polluted area around the pollution source. The suppressive effect of air pollution on the disease may be direct, the pollutants acting directly on the nematodes or indirect mediated through the host plant. Poor growth of plants and diminished root system caused by the ambient air pollution might have affected the root galling and eggmass production, because the nematodes being sedentary endoparasites entirely depend for their nutritional supply on the host plant. The nutritional status of the host plant directly affects their growth, development and reporduction (Hussey, 1985). Ambient air pollution deleteriously affect crop growth (Reinert, 1984; Heck et al., 1986). When the crop plants are adversely affected, the associated organisms which fully depend upon the host crop are liable to suffer. The direct effect of ambient air pollution may be due to toxicity of gaseous air pollutants which

enter the pore space of soil or of some heavy metals and other toxic substances like dibenzofuran and dibenzo-p-dioxime mixture reported to occur in flyash (Bhatia, 1978; Helder et al., 1982; Kamath, 1979; Sawyer, et al. 1983; Mishra and Shukla, 1986; Wong and Wong, 1986). The heavy metals like Hg, Co, Mn, B, Zn, Cd, Mo, Ni, etc. are inhibitory to various plant pathogens and soil micro-organisms (Babich and Stotzky 1982; Bisessar and Rinne, 1983; Wong and Wong, 1986). The results presented in the section II, show that ambient air pollution reduced plant growth parameters of both chick-pea and lentil due to long term exposures. The direct effects of the air pollutants or indirect efffects through the host or both operating simultaneously might be responsible for inhibition of root galling and eggmass production by the root-knot nematodes. Reduction in extensiveness of the root system might have also limited the availability of infection sites for the root-knot nematodes.

The disease incidence in the polluted area exhibited a gradation in all the directions, with the increasing distance from the pollution source. This demonstrated that the effect on the disease was directly related to the level of ambient air pollution. Since the concentrations of air pollutants with the increasing distance from the pollution source gradually became lower, the incidence and intensity of the disease increased accordingly. This was also supported by the variations observed in different directions at the

same distance from the point source, because the level of pollution and concentration of pollutants also depend upon wind direction (Thakre and Aggarwal, 1985). At the 1/2 km except in the SW direction both chick-pea and lentil were free from root-knot disease. The SW direction site at 1/2 km was very close to a colony of houses inhabited by industrial workers. Attached with the houses were kitchen gardens, grown with vegetables like tomato, eggplants, peppers etc., most preferred host crops of root-knot nematodes. The domestic waste water and water from kitchen gardens are regularly discharged in the adjacent field plots which possibly add inoculum of root-knot nematodes. This regular source of root-knot nematode inoculum might be responsible for the occurrence of the disease on the pulse crops, in fields very close (1/2 km) to the pollution source. In all other directions, the crops in the field at this distance of 1/2 km were root-knot nematode free. Similarly, the presence of a temple and hutments with kitchen gardens might have contributed to the occurrence of the disease on chick-pea in NE direction at 1 km. At 2 km, wind direction might be responsible for the variation in the intensity of the disease in E,W and NE directions. The average air pollution level was highest in E because of the wind direction for most period of the year. Hence, the disease was least. This observation demonstrated the involvement of air pollution in the incidence and intensity of the disease. At 4 km, the incidence and intensity of the disease were highest among

the polluted sites. This was most distant site included in the surveys. The observations recorded, therefore, show that air pollution in general inhibited the root-knot disea se on both the pulse crops in ambient condition. The extent of inhibition was correlated largely with the ambient levels of pollutants, which in turn was controlled by the distance from the source and wind direction. The intensity and incidence of the disease also varied between the two crops-chick-pea and lentil. The relative sensitivity of the plants to ambient air pollution may be implicated as possible cause for this variation.

Root nodulation on both the crops was also generally inhibited in the vicinity of the thermal power plant, the source of ambient air pollution. Air pollutants both in ambient and artifical treatment conditions have been demonstrated to be inhibitory for root nodulation in legumes (Reinert and Weber, 1980; Kumar, 1986). The extent of inhibition, like root-knot disease, showed a correlation with the distance from the pollution source and direction, because of variations in levels of the air pollution. The root nodulation gradually increased with the increasing distance from the pollution source. This trend was more evident in usual wind-ward direction i.e., west to east. The adverse effect of the air pollution on plant growth might be impli cated as a controlling factor for reduced root nodulation. Ambient air pollution also apperantly looked inducing death of the

nodules. The toxicity of gaseous and particulate air pollutants mainly flyash containing toxic substances including heavy metals might be implicated as direct factor for inhibition in root nodulation. The air pollutants including flyash are inhibitory for several microorganism (Darley and Middleton, 1966; Heagle, 1973, 1982; Babich and Stotzky, 1982). Even at 4 km distance, the nodulation was suppressed. This shows that Rhizobium is quite sensitive to the ambient air pollution caused by coal-burning. Infection of root nodules by root-knot nematodes was also found to be influenced by the ambient air pollution. In the area with high pollution level the infection of root nodules was less than in the area with lower level. The observations show a very significant effect of ambient air pollution. Root nodulation was suppressed, senescence of nodules was accelerated, increase of non-functional nodules occurred and infection of nodules by root-knot nematodes on both the crops was inhibited. The total effect of these influences will reflect in nitrogen fixing efficiency. Therefore, ambient air pollution caused by coal-fired thermal power plants is harmful for Rhizobium-legume symbiotic nitrogen fixing system.

The incidence and intensity of root-knot disease on chick-pea and lentil seemed to be directly correlated with the ambient air pollution in the vicinity of pollution source. The incidence and intensity of disease were reduced by the ambient air pollution depending upon the pollution

level in the area.

SUMMARY

Foliage of chick-pea and lentil grown in fields around the Thermal Power Plant, Kasimpur exhibited some air pollution induced symptoms like leaf chlorosis and necrosis of leaf margins. Chick-pea showed less sensitivity to the air pollution than lentil. At some sites where necrosis of leaf margins appeared on the lentil, no such symptom was evident on chick-pea. The intensity of the symptoms on the crops was related to the pollution level of a given site. The chlorosis and necrosis of leaf margins appeared on the leaves of both the crop plants, at the closest site (1/2 km). The symptoms became gradually less with the increasing distance.

The root nodulation by Rhizobium was suppressed by the ambient air pollution and the inhibition was concentration dependent. Root nodulation gradually declined with the decreasing distance from the pollution source. The air pollution also promoted the senescence of the root nodules. Greater number of non-functional nodules was recorded in the close vicinity of the thermal power plant. Infection of root nodules by the root-knot nematodes was also suppressed by the air pollution. Less infection occurred in the close vicinity of the pollution source. At the sites, with low pollution levels, nodule infection by the nematodes

appeared to be promoted.

The crop fields of chick-pea and lentil were found infested with two species of root-knot nematodes, M. incognita and M. javanica. The severity of the disease was more on chick-pea than lentil. Root-galling (number of galls/root system) and eggmass production (number of eggmasses/root system) were greater on chick-pea than lentil. Severity of the root-knot disease varied in different directions and distances from the pollution source and the disease severity was related to the level of the ambient pollution, which was found to be regulated by the direction and distance from the point source. In general, the root-knot disease was suppressed by the ambient air pollution caused by the thermal power plant. With the increasing distance from the pollution source, the disease severity in terms of root-galling and eggmass production declined gradually, in any particular direction. At the closest site (1/2 km) included in the observation, crops were free from the disease.

The observations indicate that the ambient air pollution caused by the Thermal Power Plant, Kasimpur suppressed root nodulation and root-knot disease on chick-pea and lentil and induced chlorosis and marginal necrosis of the leaves. These effects were related to the level of the pollution which was regulated by the distance and direction from the pollution source.

SECTION II

INTERACTION OF AMBIENT AIR POLLUTION, ROOT-KNOT NEMATODES AND ROOT NODULE BACTERIA ON CHICK-PEA AND LENTIL

The interaction of ambient air pollution, caused by the Thermal Power Plant, Kasimpur, root-knot nematodes and root nodule bacteria was studied on chick-pea and lentil in artificial inoculations at two study sites in nethouses, located at 1/2 km and 2 km away from the stack of the thermal power plant, in east-ward direction. The air pollution monitoring for determining the concentration of SO_2, NO_2 and suspended particulate matter and particulate matter deposition during the experimentation period was done at both the sites. Additionally, impact of the ambient air pollution on seed germination and post-emergence mortality of the seedlings of chick-pea and lentil were also assessed.

MATERIALS AND METHODS

Two sites in the polluted area-K_1 and K_2, 1/2 km and 2 km away respectively from the stack of the Thermal Power Plant, Kasimpur (source of ambient air pollution) were selected as the study sites. A nethouse at each site was fabricated for the study.

Air Pollution Monitoring

The concentration of SO_2, NO_2, and suspended parti-

culate matters (SPM) and flyash deposition at both the sites (K_1 and K_2) around the Thermal Power Plant, Kasimpur were determined fortnightly for the experimental period (November - March). Samplings were done by High Volume Air Sampler (Envirotech, New Delhi). The sampled air, having different pollutants, was analysed according to the procedures mentioned in the Course Manual of National Environmental Engineering Research Institute (NEERI), Nagpur, India (Anon., 1986).

Sampling of air

The sampling of air was done at the rate of 2 lit. of air/min. 4 h by using different absorbing media for different gases.

Gaseous air pollutant	Absorbing media for sampling
SO_2	Sodium tetra chloromercurate solution
NO_2	Sodium hydroxide sodium arsenite solution

The suspended particulate matter was collected over Whatman microfilter paper of grade GF/A.

Analysis of SO_2

Analysis of SO_2 in samples was done by Weast and Fack Method (being used at NEERI).

Calibration of standard curve

Standard metabisulphite was pipetted in graduated amounts (such as 0.1, 0.2, 0.3, 0.5, 0.7, 0.9, 1.0, 1.1, 1.2, 1.5 ml for containing 1,2,3,5,7,9,10,11,12,15 g SO_2 respectively) into a series of impingers or graduated nessler tubes. Absorbing medium was added into tubes to make the volume 10 ml. In the blanks, 10 ml absorbing medium was added. Then 1 ml sulphamic acid, 2 ml formaldehyde solution, 5 ml rosaniline hydrochloric solution were added one by one, and after adding each, the solution was shaken gently. After it, the volume in each impinger was maintained with double distilled water to 25 ml. After 30 min. but before 60 min. the transmittance was determined at 550 nm in spectrophotometer. A standard curve was drawn between transmittance and concentration of SO_2.

Estimation

Ten ml of sampled absorbing media was taken in impinger. Then 1 ml sulphamic acid, 2 ml formaldehyde solution and 5 ml rosaniline hydrochloric solution were added one by one after adding each, the solution was shaken gently. After 30 min., transmittance was determined at 550 nm in spectrophotometer. In the control (blank), in place of absorbing media with sampled air, absorbing media without any air was taken. The µg of SO_2 was determined by placing of transmittance (%) in calibrated standard

curve, the corresponding value (µg SO_2) was found out. SO_2 µg/m^3 was calculated according to the following formula:

$$SO_2\ \mu g/m^3 = \frac{\mu g \text{ of } SO_2}{\text{volume of air samples (lit.)}} \times 10^3$$

Volume of air sampled = Flow rate of air x time of sampling (min.)

$$SO_2\ ppm = \frac{\mu g/m^3 \times 22400}{M \times 10^6}$$

M = Molecular weight of SO_2

Analysis of NO_2

NO_2 was estimated by the analytical method.

Standard curve

0.5, 1.0, 1.5, 2.0, 2.5 and 3.0 ml of standard nitrite were taken into test tubes followed by the additional 1 ml H_2O_2 solution , 10 ml sulfanilamide solution and 1.4 ml NEDA solution. Side by side the control was also run. Test tubes were shaken and allowed to remain at stand for 10 min. for the colour development. Then after % transmittance (T) was read at 540 nm. A curve was drawn between concentration and % T.

Estimation

Ten ml of absorbing medium with sampled air was taken in the test tube. 1 ml H_2O_2 solution, 10 ml sulfanila-

mide solution and 1.4 ml NEDA solution were added in the test tube. Side by side in control (blank), absorbing media without any air was used. Test tubes were shaken and allowed to remain at stand for 10 min. for the development of colour. Then transmittance (%) was taken at 540 nm and the concentration of NO_2 was estimated from the standard curve. Then NO_2 $\mu g/m^3$ was calculated according to the following formula :

$$NO_2\ \mu g/m^3 = \frac{\mu g \text{ of } NO_2}{\text{Volume of air sample (lit.)}} \times 10^3$$

$$NO_2\ (ppm) = \frac{\mu g/m^3 \times 22400}{M \times 10^6}$$

M = Molecular weight of NO_2

Suspended particulate matter (SPM)

Amount of SPM mg/m^3 of air was determined by the High Volume Air sampler. The weight of a Whatman microfilter paper of grade GF/A of specific size was taken after putting it into dessicator for 12 h (W_1). Then the filter paper was fitted in the air sampler at the sampling site. The air sampler was run for 8 h. After sampling, filter paper was carefully folded and placed into envelope and brought to the laboratory, and kept in dessicator for 12 h and weighed (W_2). SPM mg/m^3 of air was calculated according to the following formula :

Weight of SPM in g (W) = $W_2 - W_1$

$$\text{SPM mg/m}^3 = \frac{W}{\text{Volume of air sampled (lit.)}} \times 10^3$$

Particulate matter fall

The amount of particulate matter fall (flyash depositon) at the polluted sites during the experimental period was determined. Oven dried glass jars after weighing (W_1) were placed at the sampling sites on the stand 1 m above the ground level guarded by grill frame. The upper portion of jar as well as of grill frame were kept open to allow dust fall. In the jar 1 lit. distilled was added. This volume of water was maintained in jar for one month. After one month jars were brought to the laboratory and water was evaporated by keeping in an oven. The weight of the jar having particulate mater (W_2) was taken and the total dust fall per m^2 was calculated.

$$\text{Particulate matter fall } (\text{mg/m}^2\text{/month}) = \frac{W_2 - W_1}{\text{cross section area of jar in m}^2}$$

Seed germination and Seedling mortality

To assess the impact of ambient air pollution on the seed germination of chick-pea and lentil, 100 healthy seeds of each i.e.,chick-pea, Cicer arietinum L.(cv.T-3) and

lentil Lens culinaris Medic. (cv. T-36) were sown in steam-sterilized unpolluted soil collected from the unpolluted area at both the nethouses, located 1/2 km and 2 km away from the stack of the Thermal Power Plant, Kasimpur. The control set was kept in unpolluted air, in a glasshouse at the university campus. After seven days of sowing, the number of successfully germinated seeds and the seedling which died after emergence (post-emergence mortality) were counted.

Isolation of Rhizobium

Rhizobium was isolated spearately from chick-pea and lentil roots collected from fields. The root system was washed clean and a well formed healthy pinkish nodule on the tap root was carefully cut out with a portion of root attached to the nodule. The nodule was surface sterilized for 5 min. in 0.1% mercuric chloride and repeatedly washed with sterilized water to remove the chemical. The nodule was then washed in 70% ethyl alcohol for 3 min. followed by more washing with sterilized water (Ash and Allen, 1948). The nodule was then crushed with sterile glass rod in a small aliquot of sterilized water. This suspension was further diluted for obtaining distinct colonies. Congo red yeast-extract mannitol agar medium (CRYMA) of the following constituents was used for isolation.

Mannitol, 10.0 g; K_2HPO_4, 0.5 g; $MgSO_4.7H_2O$, 0.2 g; NaCl, 0.1 g; Yeast extract, 1.0 g; Agar agar 20.0 g; Distilled water 1000 ml; Congo-red (1%), 2.5 ml.

One ml of the dilution was added in each petriplate containing 15 ml of CRYMA medium. The petriplates were incubated at 28°C (± 2) for one week. Distinct white, transluscent, glistening, elevated colonies of Rhizobium developing on the medium in petriplates were picked up and purified by reculturing.

Plant testing method

As variations are found in strains of Rhizobium, it is necessary to determine the ability of a particular isolate to produce nodules on a suitable host legume. Similarly, it is also essential to know if the nodules possess efficient nitrogen fixing ability. This was ascertained by plant testing method (SubbaRao, 1975). Plants for testing were grown on agar slants, containing nitrogen-free medium : $CaHPO_4$, 1.0 g; K_2HPO_4, 0.2 g; $MgSO_4.7H_2O$, 0.2 g; NaCl, 0.2 g; $FeCl_3$, 0.1 g; agar agar; 8.0 g; distilled water 1000 ml (Jensen, 1942) and inoculated with the desired isolates. At regular intervals, seedlings were fixed in 4% formalin and examined later under microscope for infection threads in root hairs and emergence of nodule primordia on the roots.

In another set, the test was continued for several weeks for obtaining the effectiveness of Rhizobium isolate by examining the dry weigtht of the plants. The dry weight of plant is proportional to its N-content (Erdman and Means, 1952). During the test the quarter strength nutrient solution was added to moisten the slant at the regular intervals. Uninoculated seeds with Rhizobium grown on slants in N-free medium served as control.

Pure culture of Rhizobium

Yest extract mannitol agar (YMA) was used for pure culturing of Rhizobium (Fred et al., 1932). The YMA contained K_2HPO_4, 0.5 g; $MgSO_4.7H_2O$, 0.2 g; NaCl, 0.1 g; Mannitol, 10.0 g; Yeast extract, 0.4 g; Agar agar, 15.0 g; Distilled water, 1000 ml.

The medium was autoclaved at 15 lb. p.s.i. (121°C) for 20 min. and poured in sterilized culture tubes. After solidification of the medium, the agar slants were inoculated with the tested Rhizobium isolate in aseptic condition (at laminar flow bench), and incubated at 28 °C (± 2). Rhizobium colonies were found growing in about seven days.

Soil based culture

For inoculating the legumes in pots, the soil based culture of Rhizobium was used for seed dressing (bacterization), prior to sowing.

For culturing Rhizobium in soil, the soil and compost in the ratio of 1:1 was used. 1 kg of soil-compost mixture was autoclaved and the pH was maintained at 7 by mixing 10 gm of $CaCO_3$. Then 10 g sugar (commercial) and 0.5 g K_2HPO_4 were added in soil-compost mixture. Pure culture of Rhizobium was then mixed with the soil-compost mixture thoroughly. This mixture of Rhizobium and soil-compost was used for inoculating the seeds.

Rhizobium inoculation (bacterization of seeds)

Seeds of chick-pea and lentil were bacterized with their respective strains of Rhizobium. For bacterization of seeds, commercial sugar and water were added in the soil based culture with thorough mixing. The pulse seeds were treated with this mixture followed by the drying in shade for about half an hour before sowing.

Pure culture of Root-knot Nematodes

Pure culture of the root-knot nematode species, Meloidogyne incognita and M. javanica encountered during the survey were raised and maintained in greenhouse. In order to make pure culture of each species of the root-knot nematodes, single eggmass of each was added separately in pots, having sterilized soil around the roots of a young tomato or eggplant seedling. Inoculated pots were maintained in glasshouse. Sub-culturing was done approximately every

2 to 3 months by inoculating new tomato or eggplant seedlings with atleast 15 eggmasses, each obtained from the pure culture in order to maintain sufficient inoculum for their identification and use in experiments.

Preparation of inoculum and inoculation

For conducting experiments with root-knot nematodes, inoculations of plants were done by using freshly hatched second stage juveniles (J_2). Second stage juveniles were obtained by incubating eggmasses collected from roots of tomato or eggplant maintaining pure populations of the root-knot nematodes in sterilized water 25°C. After 72 h, number of the hatched juveniles (J_2) per ml was standardized by counting the juveniles from ten, 1 ml samples and the average number was used to represent the number of juveniles per ml. After counting, the measured volume of the nematode suspension according to the level of inoculum required for the experiment, was pipetted out and added in the pots after making depression in soil near the seedlings.

INTERACTION STUDIES

The interaction of ambient air pollution, root-knot nematodes and root nodule bacteria on chick-pea and lentil was studied separately in pots kept in two nethouses in the polluted area, 1/2 km (K_1) and 2 km (K_2) away from the Thermal Power Plant, Kasimpur, in east-ward direction.

Plant culture and treatments

To conduct the experiment, steam sterilized soil was filled in 30 cm clay pots. In one half of the pots, 10 seeds of chick-pea (cv. T-3) and lentil (cv. T-36) bacterized with Rhizobium were sown in each pot and in other half of the pots 10 non-bacterized seeds in each pot were sown. After 10 days, the seedlings were thinned to one in each pot.

Inoculation by Meloidogyne incognita or M. javanica was done after one month of sowing. The inoculum level was 1000 J_2 pot. The following were the six treatments for each crop (chick-pea/lentil). All the treatments were replicated five times.

T_1 = Control (crop plant)

T_2 = Crop plant + Rhizobium

T_3 = Crop plant + Meloidogyne incognita

T_4 = Crop plant + Rhizobim + M. incognita

T_5 = Crop plant + M. javanica

T_6 = Crop plant + Rhizobium + M. javanica

One set of pots (of all the six treatments) were kept in a nethouse at 1/2 km away (K_1) from the stack of the Thermal Power Plant. Another set of pots of treatments

was kept in a nethouse at 2 km away (K_2) from the stack. A similar set of pots with same treatments were also kept in unpolluted air in glasshouse. The experiment was terminated after 100 days of inoculations.

PARAMETERS

Plant Growth and Yield

At termination of the experiment, lengths of shoot and root of plants of both the crops from each treatment were measured and their fresh and dry weights were determined. For determining the dry weight, root and shoot of each plant from the treatments were wrapped in blotting sheets and dried in a hot air oven at 80°C for 24 h and weighed.

Root-knot disease and Root nodulation

At the termination of the experiment, the number of galls and eggmasses/root system in different treatments of each crop were counted. Similarly, number of functional and total nodules and nodules infected with root-knot nematodes in each treatment of the experiment on both the crops were determined.

Leaf Pigments

Chlorophyll content of leaves of chick-pea and lentil from different treatments of the experiment was estimated.

For chlorophyll estimation, 1 g of leaves were ground in 40 ml 80% acetone with the help of mortar and pestle. The suspension was decanted in buchner funnel having two Whatman paper No. 1. Then filtration was done with the help of suction pump. The residue was ground thrice adding with 30, 20 and 10 ml of acetone respectively. The suspension was decanted in buchner funnel and filtered in vaccum. At last mortar and pestle were rinsed with 80% acetone, transferred in buchner funnel and filtered in vaccum. The filtrate was transferred in 100 ml volumetric flask and the volume was made upto capacity, the transmittance was read at 645 and 663 nm at spectrophotometer. The chlorophyll a,b and total chlorophyll were calculated accordingly by using optical density, (O.D.) (% transmittance) (Mackinney, 1941).

Leaf Epidermal Characters

To study leaf epidermal characters, peelings of epidermis from both surfaces (lower and upper) of leaves of chick-pea and lentil from different treatments of the experiment were prepared and stained and mounted for microscopic examination.

Preparation of leaf peeling

Leaf peeling was prepared by the method given by Ghouse and Yunus (1972). Leaf portions were boiled in 40%

HNO_3 for 2-3 min. When the epidermis of both the surface of leaves had separated, epidermal peelings were washed thrice in water and transferred to 20% KOH for 15 min. which neutralized the acid. After washing, the peelings were ready for staining.

Staining

The washed epidermal peelings were kept in 30% alcohol for 10 min. and then transferred in 50% alcohol for 5 min. The peelings were then stained with bismark brown (in 50% alcohol) for 12 h. At the end of this period, the peelings were washed with 50% alcohol, 3 times, with 5 min. intervals and passed through a series of 70%, 90% and absolute alcohol + xylene and xylene. The peelings were mounted in Canada balsam.

The slides were examined under light microscope. The number of stomata, trichome-hydathodes (only in chick-pea) and trichomes on lower and upper leaf surfaces were counted and their number per cm^2 was calculated. The size of stomata and stomatal aperture and the length of trichome-hydathodes and trichomes were measured on both leaf surfaces.

Seed Proteins

The protein content of seeds of chick-pea and lentil from different treatments of the experiment was estimated by using the method given by Lowry et al., (1951).

Following reagents were prepared for estimating soluble and insoluble protein contents of the seeds.

Reagent A - 2% sodium carbonate in 0.1N NaOH in ratio of 1:1

Reagent B - 0.5% $CuSO_4$ in 1% sodium tarterate in ratio of 1:2

Reagent C - 50 ml reagent A + 1 ml reagent B

(alkaline $CuSO_4$)

Reagent D - 50 ml of 2% sodium carbonate + 1 ml reagent B

(Carbonate $CuSO_4$ solu.)

Reagent E - Follin's reagent diluted to make 1 N acid

(diluted Follin's reagent)

Standard curve

Before actual estimation, standard curve was prepared by dissolving 40 mg of egg albumin in 0.1N NaOH solution. The volume was made upto 100 ml. 0.1 ml to 1 ml solution was taken in 10 test tubes. Reagent A was added to the test tubes. After 10 min. 0.5 ml reagent E was added. The % transmittance was read at 660 nm and standard curve was drawn between O.D. and concentrations.

Soluble protein

Fifty mg dry powder of seeds was ground with 5 ml of double distilled water in mortar with pestle. Then water extract was decanted in centrifuge tube for centrifugation

at 4000 rpm for 10 mın. Then supernatent was collected ın 50 ml volumetrıc flask and the resıdue was retaıned ın centrıfuge tube for estımatıng ınsoluble proteın. After makıng the volume upto 50 ml, 1 ml of water extract was transferred ın a 10 ml test tube followed by addıtıon of 5 ml of reagent C. After mıxıng, solutıon was left as such for 10 mın. Then 5 ml of reagent E was added and mıxed ımmedıately. The control was run along wıth the experımental set. Per cent transmıttance was read at 660 nm after half an hour. The correspondıng protein content was measured, by usıng the standard curve.

Insoluble protein

The resıdue retaıned ın the centrıfuge tube was used for ınsoluble protein estımatıon. 5 ml of 5% trıchloro-acetıc acıd was added to the resıdue wıth shakıng. After half an hour ıt was centrıfuged at 4000 rpm to 10 mın. The supernatent was dıscarded. 5 ml of 1N NaOH was added ın the resıdue wıth vıgorous shakıng and kept ın waterbath for about an hour. After coolıng ıt was agaın centrıfuged and supernatent was collected ın 50 ml volumetrıc flask and volume was made upto wıth 1N NaOH. 1 ml of thıs solutıon was taken ın test tube wıth 5 ml of reagent D followed by mıxıng. After 10 mın 0.5 ml of reagent L was added wıth ımmedıate mıxıng. 1N NaOH was used ın control. Per cent transmıttance was read at 660 nm after 30 mın. The protein

content was calculated by using the standard curve.

RESULTS

Air quality

The ambient air of the Thermal Power Plant, Kasimpur, contained air pollutants like SO_2, NO_2 and suspended particulate matter (SPM). Their concentration was greater at K_1 than K_2, 1/2 km and 2 km away respectively, from the stack (Table 1). The concentration of SO_2 ranged between 0.0064 and 0.1643 ppm with an average of 0.08165 ppm at K_1 and between 0.0026 and 0.059 ppm with an average of of 0.0302 ppm at K_2. The range of NO_2 concentration was 0.0039 ppm to 0.0992 ppm at K_1 (average 0.04967 ppm) and 0.0011 ppm to 0.0323 ppm at K_2 (average 0.0163 ppm). The concentration of suspended particulate matter (SPM) ranged between 0.314 and 3.046 mg/m^3 at K_1 and between 0.137 and 2.683 mg/m^3 at K_2. The average was 1.680 and 1.410 mg/m^3 at K_1 and K_2 respectively. The deposition of particulates, mainly flyash and a small amount of coal dust and soil particles, was also greater at K_1 (389.15 mg/m^2/month) than K_2 (210.75 mg/m^2/month) (Table 1).

Table 1. Concentration of air pollutants at the two polluted sites around the Thermal Power Plant, Kasimpur during winter (November - March).

Air pollutants	K_1 (1/2 km) Conc. range	Average conc.	K_2 (2 km) Conc. range	Average conc.
SO_2 (ppm)	0.0064-0.1643	0.08165	0.0026-0.0591	0.0302
NO_2 (ppm)	0.0039-0.0992	0.04967	0.0011-0.0323	0.0163
SPM (mg/m^3)	0.314 -3.046	1.680	0.137 -2.683	1.410
Flyash deposition mg/m^2/ month	389.15		210.75	

Seed germination

The ambient air pollution adversly affected seed germination of both chick-pea and lentil. The adverse effect

Table 2. Effect of ambient air pollution on seed germination and post-emergency mortality of the seedlings of chick-pea and lentil.

Sites	Chick-pea Germination %	Reduction over control %	Seedling mortality %	Lentil Germination %	Reduction over control %	Seedling mortality %
Control	90	-	2	86	-	3
K_1 (1/2 km)	55	38.89	14	56	34.88	18
K_2 (2 km)	66	26.67	10	65	24.42	13

on seed germination was greater at K_1 than K_2. At K_1

reduction in seed germination was 38.89% and 34.88% in chick-pea and lentil respectively, and at K_2 26.67% and 24.42% respectively. At both the polluted sites, post-emergenece mortality of seedlings was greater than at the control site. Inhibition of seed germination was greater in chick-pea than lentil while the moratlity of seedlings was greater in lentil than chick-pea at both the sites (Table 2).

CHICK-PEA, Cicer arietinum L.

Plant growth and yield

Plant growth of uninoculated plants of chick-pea was adversely affected by the ambient air pollution. The adverse effect was greater at K_1 than K_2. All the considered growth parameters at K_1 were significantly smaller than the check plants at the unpolluted site. At K_2 the reductions in length of root, fresh weights of both shoot and root and dry weight of shoot were significant at $P = 0.01$ while the reductions in length and dry weight of root were significant only at $P = 0.05$. Inoculation of Rhizobium increased the plant growth of chick-pea. All the growth parameters were significantly greater ($P = 0.01$) in the plants inoculated with Rhizobium at the unpolluted site in comparison to plants without Rhizobium. M. incognita at the unpolluted site caused significant reduction in plant growth parameters. The reduction in dry weight of

Table 3. Interactive effects of ambient air pollution, root-knot nematodes and root nodule bacteria on plant growth and yield characters of chick-pea.

Treatment		Length (cm)			L.S.D.		Fresh weight (g)			L.S.D.		Dry weight (g)			L.S.D.		Flower/Fruit			L.S.D.	
		C	K_1	K_2	0.01	0.05	C	K_1	K_2	0.01	0.05	C	K_1	K_2	0.01	0.05	C	K_1	K_2	0.01	0.05
P (Control)	S	32.6	18.4	24.2	4.16	2.86	25.25	17.50	20.50	2.24	1.54	5.80	4.05	4.75	0.52	0.36	FL 96.8	35.6	58.8	7.91	5.44
	R	22.7	16.3	20.5	2.07	1.42	17.50	12.75	15.05	1.00	0.69	4.15	3.55	3.90	0.39	0.27	FR 64.6	15.6	36.4	6.39	4.39
P+Rh	S	42.4	21.5	29.4	4.47	3.07	38.55	23.10	28.70	3.07	2.11	8.95	5.30	6.85	0.61	0.42	FL150.4	47.0	85.2	9.06	6.23
	R	27.5	18.1	23.8	3.16	2.17	24.25	15.30	19.50	1.75	1.20	5.75	4.35	5.05	0.55	0.38	FR110.2	23.8	58.6	8.21	5.64
P+Mi	S	25.2	16.0	19.8	3.13	2.15	21.85	16.35	18.45	1.91	1.31	5.10	3.80	4.35	0.42	0.29	FL 58.8	26.6	38.4	5.91	4.06
	R	16.4	13.6	16.4	1.08	0.74	14.80	11.80	13.05	0.77	0.53	3.45	3.35	3.40	0.31	0.21	FR 35.8	10.4	21.8	3.74	2.57
P+Rh+Mi	S	30.7	17.6	22.5	3.54	2.43	30.40	19.60	23.45	3.29	2.26	7.20	4.70	5.75	0.84	0.58	FL 70.2	29.8	44.6	7.70	5.29
	R	19.6	14.2	17.9	1.34	0.92	18.30	13.45	15.70	0.99	0.68	4.60	3.65	3.95	0.29	0.20	FR 45.4	12.2	26.4	4.58	3.15
P+Mj	S	29.3	17.2	22.5	3.90	2.68	24.15	17.15	19.90	2.88	1.98	5.45	3.95	4.60	0.49	0.34	FL 70.4	29.2	46.8	8.23	5.66
	R	19.8	15.7	19.0	1.51	1.04	16.75	12.45	14.65	0.80	0.55	3.85	3.45	3.75	0.35	0.24	FR 48.0	13.8	29.2	5.72	3.93
P+Rh+Mj	S	36.4	19.7	26.4	4.77	3.28	34.15	22.00	26.45	4.12	2.83	8.15	5.10	6.40	0.77	0.53	FL 98.2	36.4	61.4	7.16	4.92
	R	23.9	17.1	21.4	1.41	0.97	21.85	14.45	18.45	1.27	0.87	4.90	4.10	4.45	0.41	0.28	FR 67.2	16.4	38.2	6.02	4.14
L.S.D.																					
0.01	S	3.72	1.76	2.54			2.03	1.53	2.09			0.94	0.57	0.46			FL 6.30	3.72	5.48		
	R	1.73	0.98	1.54			1.55	1.01	1.40			0.63	0.35	0.53			FR 5.40	1.54	3.87		
0.05	S	2.73	1.29	1.86			1.49	1.12	1.53			0.69	0.42	0.34			FL 4.62	2.73	4.02		
	R	1.27	0.72	1.15			1.14	0.74	1.03			0.46	0.26	0.39			FR 3.96	1.13	2.84		

S = Shoot, R = Root

FL = Flower, FR = Fruit

Each value is mean of five replicates.

C = Control site, K_1 = 1/2 km away from the stack, K_2 = 2 km away from the stack. These abbreviations are common to all subsequent tables in the section.

P = Plant, Rh = Rhizobium, Mi = Meloidogyne incognita, Mj = M. javanica.

the shoot was, however, significant only at P = 0.05. M. javanica caused reduction only in shoot and root lengths, (significant at P = 0.05 and P = 0.01 respectively). The reductions in fresh and dry weights of shoot and root were not significant. M. incognita in the presence of Rhizobium did not cause significant reduction in shoot length but significant decrease occurred in root length. The fresh and dry weights of shoot and fresh weight of root were significantly (at P = 0.05) increased. The decrease observed in root dry weight was not significant. In the presence of Rhizobium, M. javanica did not cause reductions in growth parameters of plants. Instead, increases in all the growth parameters except root length were noticed in comparison to the control plants. The individual and combined effects of Rhizobium, and M. incognita or M. javanica were suppressed by the ambient air pollution. The adverse effects of the ambient air pollution were greater at K_1 than K_2 (Table 3, Fig. 1A).

The yield characters i.e. flowering and fruiting of chick-pea were significantly decreased by the ambient air pollution at both the sites. The adverse effect of ambient air pollution was greater at K_1 than K_2. Rhizobium inoculation significantly increased the number of flowers and fruits in comparison to plants without Rhizobium. M. incognita and M. javanica significantly reduced flowering and fruiting. The suppression was greater

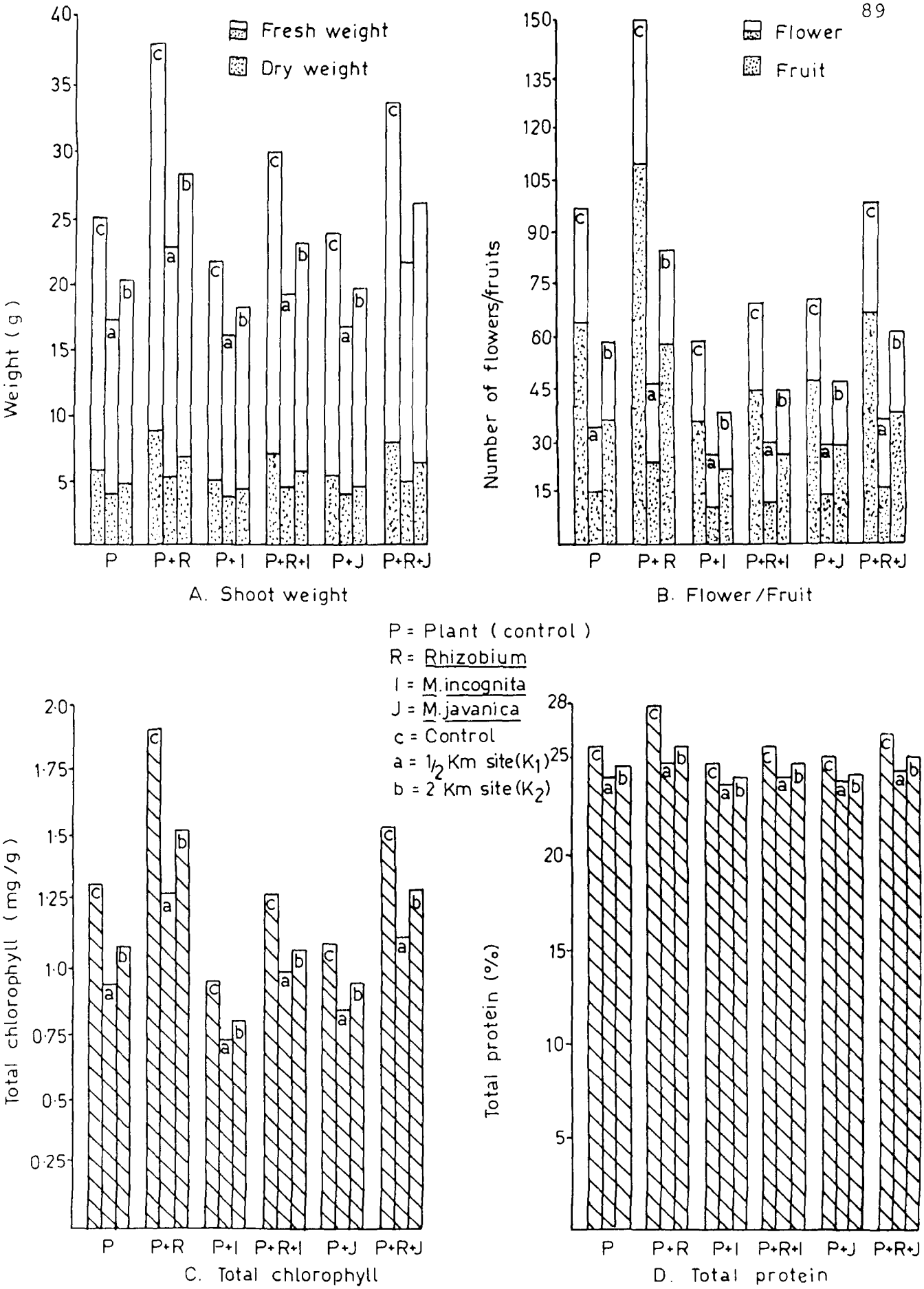

Fig. 1. Interactive effects of ambient air pollution, root-knot nematodes and root nodule bacteria on some parameters of chick-pea

due to M. incognita than M. javanica. M. incognita in the presence of Rhizobium also significantly decreased the number of flowers and fruits. But M. javanica together with Rhizobium did not cause significant reduction in the number of flowers and fruits. The ambient air pollution suppressed the individual and combined effects of Rhizobium and M. incognita or M. javanica. The suppresive effects of the ambient air pollution were greater at K_1 than K_2 (Table 3, Fig. 1B).

Root-knot disease and root nodulation

The root galling and eggmass production of the nematodes were significantly suppressed by the ambient air pollution. Root galling and eggmass production of both the species were relatively poor at the polluted sites. The suppressive effect of the ambient air pollution was greater at K_1 than K_2. In the presence of Rhizobium at the unpolluted site root galling and eggmass production of the root-knot nematodes were reduced. At the polluted sites, root galling and eggmass production of the nematodes were lowest, in the presence of Rhizobium (Table 4).

Root nodulation on chick-pea was suppressed by the ambient air pollution. The counts of total nodules and functional nodules were significantly decreased at both the polluted sites. The adverse effect of ambient air pollution was greater at K_1 than K_2. Root-knot nematodes

Table 4. Interactive effects of ambient air pollution, root-knot nematodes and root-nodule bacteria on root-galling, eggmass production, bacterial nodulation, leaf chlorophyll content and protein content in seeds of chick-pea.

Treatment		Gall/Eggmass					Nodule					Chlorophyll(mg/g)					Protein(%)				
					L.S.D.					L.S.D.					L.S.D.					L.S.D.	
		C	K_1	K_2	0.01	0.05	C	K_1	K_2	0.01	0.05	C	K_1	K_2	0.01	0.05	C	K_1	K_2	0.01	0.05
P (Control)												A 0.621	0.446	0.502	0.057	0.039	S 11.30	10.02	10.44	0.52	0.35
												B 0.571	0.409	0.471	0.061	0.042	I 14.36	14.06	14.22	0.42	0.29
												T 1.313	0.938	1.082	0.111	0.076	T 25.66	24.08	24.66	1.18	0.81
P+Rh							T 140.4	67.8	85.6	14.14	0.72	A 0.943	0.609	0.843	0.096	0.066	S 12.34	10.38	10.96	0.70	0.48
							F 120.6	49.2	68.4	13.76	9.46	B 0.878	0.553	0.658	0.081	0.056	I 15.62	14.42	14.80	0.56	0.39
												T 1.901	1.276	1.515	0.189	0.130	T 27.96	24.80	25.76	1.41	0.97
P+Mi	G	176.2	38.4	56.2	11.38	7.82						A 0.447	0.342	0.446	0.057	0.039	S 10.94	9.84	10.20	0.45	0.31
	E	108.6	18.4	28.2	7.17	4.93						B 0.412	0.318	0.349	0.044	0.030	I 13.96	13.88	13.92	0.62	0.43
												T 0.945	0.727	0.801	0.119	0.082	T 24.90	23.72	24.12	0.93	0.64
P+Rh+Mi	G	125.6	32.6	52.0	10.66	7.33	T 100.2	56.6	65.4	10.61	7.29	A 0.612	0.447	0.597	0.081	0.056	S 11.40	10.06	10.58	0.60	0.41
	E	86.4	15.6	24.4	7.52	5.17	F 70.8	33.6	42.2	9.36	6.43	B 0.559	0.413	0.462	0.068	0.047	I 14.38	14.08	14.26	0.48	0.33
							I 15.2	8.2	15.8	1.21	0.83	T 1.285	0.984	1.069	0.176	0.121	T 25.78	24.14	24.84	0.83	0.57
P+Mj	G	83.4	26.8	40.2	7.07	4.86						A 0.520	0.398	0.524	0.065	0.045	S 11.10	9.90	10.28	0.55	0.38
	E	48.6	13.8	20.4	7.13	4.90						B 0.479	0.365	0.405	0.045	0.031	I 14.06	13.98	14.02	0.47	0.32
												T 1.094	0.838	0.941	0.122	0.084	T 25.16	23.88	24.30	0.61	0.42
P+Rh+Mj	G	52.2	21.4	29.4	6.68	4.59	T 125.4	62.0	74.02	10.64	7.31	A 0.729	0.528	0.717	0.118	0.081	S 11.68	10.26	10.78	0.63	0.43
	E	33.8	13.4	18.2	4.54	3.12	F 100.6	45.4	60.0	10.33	7.10	B 0.660	0.483	0.560	0.092	0.063	I 14.72	14.22	14.48	0.60	0.41
							I 11.2	4.2	7.2	1.00	0.69	T 1.539	1.114	1.289	0.217	0.149	T 26.40	24.48	25.26	0.73	0.50
L.S.D.																					
0.01	G	8.05	3.76	4.82			T 18.46	6.23	7.03			A 0.060	0.041	0.042			S 0.65	0.44	0.56		
	E	7.40	0.50	1.18			F 13.30	5.25	5.60			B 0.057	0.040	0.035			I 0.63	0.50	0.53		
							I 3.17	2.06	2.70			T 0.106	0.087	0.085			T 0.97	0.74	0.85		
0.05	G	5.74	2.68	3.44			T 12.69	4.28	4.83			A 0.044	0.030	0.031			S 0.48	0.32	0.41		
	E	5.28	0.36	0.84			F 9.14	3.61	3.85			B 0.042	0.029	0.026			I 0.46	0.37	0.39		
							I 1.91	1.24	1.63			T 0.078	0.064	0.062			T 0.71	0.54	0.62		

G = Gall, E = Eggmass

T = Total, F = Functional
I = Infected

A = Chl.a, B = Chl.b, T = Total chl.

S = Soluble, I = Insoluble, T = Total

Each value is mean of five replicates.

also suppressed root nodulation. M. incognita was more effective in reducing the number of total and functional nodules than M. javanica. The number of nodules infected with the root-knot nematodes also significantly decreased due to ambient air pollution. At the polluted sites, root nodulation was poorest, in the presence of root-knot nematodes (Table 4).

Leaf pigments and seed proteins

The leaf pigments (chlorophyll a, chlorophyll b and total chlorophyll) and seed proteins (soluble and insoluble) were significantly reduced by the ambient air pollution (Table 4). The adverse effects of the ambient air pollution were greater at K_1 than K_2. The decrease in chlorophyll content and soluble protein content was significant at both the sites but at K_1 decrease in insoluble protein was significant only at $P = 0.05$. Reduction in total protein content was significant at $P = 0.05$ and $P = 0.01$ at K_2 and K_1 respectively. At the unpolluted site, Rhizobium inoculation significantly increased the leaf pigment and seed protein contents. M. incognita and M. javanica significantly decreased the leaf pigments. M. incognita also significantly suppressed the insoluble ($P = 0.01$) and total proteins ($P = 0.05$) but the decrease in soluble protein was not significant. M. javanica did not cause significant decrease in insoluble

and soluble protein contents, but reduction in total proteins was significant at P = 0.05. M. incognita in the presence of Rhizobium non-significantly increased the protein contents M. javanica non-significantly increased the soluble and insoluble protein contents but the increase in total protein contents was significant at P=0.05. The individual and combined effects of Rhizobium and M. incognita or M. javanica on chlorophyll and protein contents were suppressed by the ambient air pollution when compared to their respective checks at the control site. The adverse effects of the ambient air pollution were greater at K_1 than K_2 (Table 4, Figs. 1C and 1D).

Leaf epidermal characters

All the leaf epidermal characters of chick-pea considered in the study were affected by the ambient air pollution. Number of stomata and trichome-hydathodes, size of stomata and stomatal aperture and length of trichome-hydathodes were adversely affected by the ambient air pollution. The decrease in the number and size of stomata, the length of trichomes on both the leaf surfaces, size of stomatal aperture and number of trichome-hydathodes on upper surface were significant at P = 0.01 while the decrease in size of stomatal aperture and number of trichome-hydathodes on the lower surface were significant at P = 0.05 at K_2. The decreases in all the parameters of the epidermal structures at K_1 were significant

(P = 0.01). Rhizobium increased all these parameters significantly at unpolluted site in comparison to plants without Rhizobium. M. incognita significantly reduced all the parameters of epidermal characters at the unpolluted site. But M. javanica caused only significant (at P = 0.05) decrease in stomatal size on upper surface and the number and length of trichome-hydathodes on both the surfaces. No significant decrease in stomatal size on lower surface occurred. When M. incognita and Rhizobium were together, an increase in the number of stomata on the lower (significant at P = 0.01) and on the upper leaf surface (significant at P = 0.05) occurred. The increase in the size of stomata and decrease in the size of stomatal aperture due to M. incognita and Rhizobium combination were not significant. An increase in the number of trichome-hydathodes on the lower (significant at P = 0.05) and on upper leaf surface (P = 0.01) was noticed. M. javanica along with Rhizobium significantly increased the number of stomata and trichome-hydathodes, size of stomata and length of trichome hydathodes. The combined effect of M. javanica and Rhizobium on the size of stomatal aperture was not significant. The ambient air pollution suppressed the individual and combined effects of Rhizobium and M. incognita or M. javanica. The effects were greater at K_1 than K_2 (Table 5).

Table 5. Interactive effects of ambient air pollution, root-knot nematodes and root nodule bacteria on some leaf epidermal characters of chick-pea.

Treatment		No. of stomata/cm^2			L.S.D.		Size of stomata (μm^2)			L.S.D.		Size of Stomatal aperture (μm^2)			L.S.D.	
		C	K_1	K_2	0.01	0.05	C	K_1	K_2	0.01	0.05	C	K_1	K_2	0.01	0.05
P (Control)	L	24992.12	19373.74	20485.34	784.44	539.17	396.33	333.05	353.87	35.44	24.36	86.44	74.87	80.79	6.14	4.22
	U	13884.45	10361.53	11107.56	688.87	473.48	378.45	310.20	331.97	40.05	27.53	62.50	52.88	56.05	6.01	4.13
P+Rh	L	30240.45	20729.90	23353.29	654.25	518.42	459.74	366.36	397.75	43.75	29.73	96.81	79.05	88.38	5.79	3.98
	U	17160.17	11314.79	12773.69	723.84	497.52	446.57	345.56	381.77	42.44	29.17	71.88	57.64	62.55	7.30	5.02
P+Mi	L	23140.26	18700.52	19325.79	797.23	547.96	360.61	317.19	329.49	36.11	24.82	75.17	68.66	72.46	6.07	4.17
	U	12452.02	9840.01	10284.78	729.84	501.64	340.94	294.59	305.40	46.96	32.28	53.65	48.51	49.82	4.92	3.38
P+Rh+Mi	L	25916.74	19448.54	20833.20	738.91	507.88	402.27	336.22	355.85	31.15	21.41	81.19	72.46	76.80	5.35	3.68
	U	14344.72	10430.41	11241.26	783.01	538.19	387.26	312.26	335.94	38.47	26.44	59.55	51.42	54.31	5.98	4.11
P+Mj	L	23801.36	18956.69	19792.60	708.14	486.73	376.89	323.35	337.98	28.82	19.81	78.58	69.70	74.32	5.85	4.02
	U	12879.11	10049.98	10659.85	789.01	542.31	352.69	301.17	315.56	38.47	26.44	55.31	49.14	50.77	5.51	3.79
P+Rh+Mj	L	27847.42	20397.40	22365.64	766.11	526.57	429.65	348.57	375.16	38.12	26.20	86.59	74.01	80.57	6.17	4.24
	U	15352.25	10934.38	12056.29	780.96	536.78	410.12	328.27	354.06	37.89	26.04	61.95	52.59	55.54	5.67	3.90
L.S.D.																
0.01	L	678.46	562.23	535.60			29.42	20.29	24.44			7.80	6.91	7.08		
	U	520.92	419.40	504.33			31.48	25.12	26.98			6.59	6.36	6.53		
0.05	L	497.46	412.24	392.71			21.57	14.88	17.92			5.72	5.07	5.19		
	U	381.95	307.51	369.78			23.08	18.42	19.78			4.83	4.66	4.79		

L = Lower surface, U = Upper surface

Each value is mean of five replicates.

Table 5. (Continued)

		No. of trichomes-hydathodes/cm^2					Length of trichomes-hydathodes (µm)					No. of trichomes/cm^2					Length of trichomes (µm)				
					L.S.D.					L.S.D.					L.S.D.					L.S.D.	
		C	K_1	K_2	0.01	0.05	C	K_1	K_2	0.01	0.05	C	K_1	K_2	0.01	0.05	C	K_1	K_2	0.01	0.05
P (Control)	L	651.39	547.39	561.54	90.47	62.18	424.56	371.93	385.45	31.53	21.67	3039.57	4012.23	3799.46	428.50	294.52	331.25	284.36	371.04	29.69	20.41
	U	411.40	334.47	348.64	52.75	36.26	404.13	336.89	346.78	44.62	30.67	1651.24	2229.17	2110.28	259.39	178.29	320.75	381.92	366.79	36.63	25.18
P+Rh	L	1097.02	766.35	876.02	86.35	59.35	562.22	442.59	485.67	35.37	24.31	1885.59	2928.64	2549.73	351.85	241.84	238.65	287.61	287.61	34.39	23.64
	U	828.16	495.02	564.80	116.13	79.82	545.76	419.74	431.08	53.70	36.91	988.62	1569.84	1388.34	307.67	211.47	230.11	303.11	275.78	41.06	28.22
P+Mi	L	497.24	459.97	452.85	84.11	57.81	375.22	357.62	353.62	35.03	24.08	3556.30	4413.45	4289.59	293.25	201.56	371.00	407.31	402.91	31.96	21.97
	U	304.74	276.07	283.26	38.42	26.41	351.42	311.94	315.36	42.69	29.31	2030.73	2541.25	2511.23	239.04	164.30	380.93	412.47	409.34	29.67	20.39
P+Rh+Mi	L	721.00	597.98	629.47	96.37	66.24	446.51	376.23	403.13	32.87	22.59	2694.17	3740.21	3459.35	281.97	193.81	304.10	370.28	347.33	39.41	27.09
	U	624.72	363.41	399.40	44.45	30.55	428.73	343.13	365.82	36.05	24.78	1430.09	2082.99	1931.72	222.80	153.14	322.82	374.98	362.25	36.10	24.81
P+Mj	L	552.03	504.97	496.94	75.25	51.72	388.90	357.63	362.27	34.68	23.84	3372.92	4252.96	4118.61	268.68	184.67	361.06	399.62	398.45	45.77	31.46
	U	340.04	304.06	308.74	36.81	25.63	364.08	317.82	321.09	45.16	31.01	1925.16	2429.80	2378.29	264.15	181.56	367.68	405.60	402.12	39.98	27.48
P+Rh+Mj	L	866.69	701.91	730.50	86.23	59.27	482.24	400.54	429.65	39.95	27.46	2249.28	3217.51	2840.42	331.08	227.56	284.29	350.54	332.05	37.57	25.82
	U	782.14	431.77	463.13	77.92	53.56	460.56	348.60	362.83	41.00	28.18	1212.43	1799.85	1585.52	164.46	113.04	285.02	346.67	329.51	33.49	23.02
L.S.D.																					
0.01	L	97.45	85.10	93.30			40.53	38.08	37.52			173.80	267.98	281.92			31.04	33.13	28.48		
	U	90.27	69.92	91.80			47.58	34.33	40.04			171.41	275.14	200.88			37.38	53.41	41.58		
0.05	L	71.45	69.73	65.41			29.72	27.92	27.51			127.43	196.49	206.71			22.76	24.29	20.88		
	U	66.19	51.27	67.31			34.89	25.17	29.36			125.68	201.74	147.29			27.41	39.16	30.49		

L = Lower surface, U = Upper surface

Each value is mean of five replicates.

The number and length of trichomes were increased significantly at both the polluted sites. The increases were greater at K_1 than K_2. Rhizobium significantly reduced the number and length of trichomes at the unpolluted site. Inoculation of M. incognita or M. javanica caused significant increase in the number and length of trichomes. M. incognita or M. javanica together with Rhizobium significantly reduced the number of trichomes. An increase in trichome length on the lower surface (significant at $P = 0.05$) due to combined effect of M. incognita and Rhizobium occurred. The increase in length of trichomes on upper surface was, however, not significant. M. javanica together with Rhizobium decreased trichome length significantly at $P = 0.01$ on lower and at $P = 0.05$ on upper leaf surface. The individual and combined effects of Rhizobium and M. incognita or M. javanica were suppressed by the ambient air pollution, being greater at K_1 than K_2 (Table 5).

LENTIL, Lens culinaris Medic.

Plant growth and yield

The ambient air pollution adversely affected all the plant growth and yield parameters of lentil. The trend in reductions in growth and yield characters of lentil was similar to that of chick-pea. Plant growth and yield of lentil were reduced significantly at both K_1 and K_2 ,

the polluted sites. The reductions were greater at K_1 than K_2 (Table 6).

Addition of Rhizobium at the unpolluted site significantly increased all the growth and yield parameters of lentil but M. incognita significantly suppressed plant growth and yield. M. javanica also affected similarly, but reduction in dry weight of shoot was significant only at P = 0.05 and decrease in flowering and fruiting was not significant. When Rhizobium was present together with M. incognita, only decrease in length of shoot and root (significant at P = 0.01 and P = 0.05 respectively) occurred. Significant increases in dry weight of root (at P = 0.01) and number of fruit (at P = 0.05) were also recorded. M. javanica along with Rhizobium significantly increased the growth and yield parameters except the shoot length. The individual and combined effects of Rhizobium and M. incognita or M. javanica were suppressed by the ambient air pollution. The ambient air pollution in this respect was more effective at K_1 than K_2 (Table 6, figs. 2A and 2B).

Root-knot disease and root nodulation

M. incognita caused greater root galling and eggmass production on lentil than M. javanica. Like chick-pea, the gall formation and eggmass production of both the species on lentil were significantly reduced by the ambient

Table 6. Interactive effects of ambient air pollution, root-knot nematodes and root nodule bacteria on plant growth and yield characters of lentil.

		Length(cm)					Fresh weight(g)					Dry weight(g)					Flower/Fruit				
					L.S.D.					L.S.D.					L.S.D.					L.S.D.	
		C	K_1	K_2	0.01	0.05	C	K_1	K_2	0.01	0.05	C	K_1	K_2	0.01	0.05		C	K_1	K_2	0.01	0.05
P (Control)	S	31.2	13.6	18.5	3.30	2.27	16.5	6.45	9.25	1.19	.0.82	3.15	1.60	2.10	0.33	0.23	FL	52.4	13.4	21.6	5.85	4.02
	R	17.0	8.3	12.5	1.63	1.12	12.5	4.65	7.20	0.97	0.67	2.85	1.05	1.55	0.32	0.22	FR	35.8	7.6	12.2	4.12	2.83
P+Rh	S	38.7	15.4	21.8	3.10	2.13	23.75	8.40	12.85	1.59	1.09	4.65	2.05	2.85	0.45	0.31	FL	80.2	18.0	31.4	9.55	5.19
	R	21.5	9.3	14.7	1.82	1.25	19.6	6.60	10.80	1.72	1.18	4.25	1.45	2.25	0.39	0.27	FR	60.2	11.4	19.2	5.08	3.49
P+Mi	S	24.2	11.5	14.9	3.56	2.45	12.95	5.40	7.50	1.06	0.73	2.55	1.35	1.75	0.31	0.21	FL	42.2	11.4	18.2	6.23	4.28
	R	13.3	7.0	10.2	1.50	1.03	8.75	3.50	5.20	0.92	0.63	2.35	0.95	1.30	0.28	0.19	FR	26.4	6.0	9.4	3.52	2.42
P+Rh+Mi	S	27.5	12.5	16.6	3.97	2.73	16.4	6.35	9.05	1.19	0.82	3.25	1.65	2.15	0.42	0.29	FL	57.4	14.6	23.8	5.76	3.96
	R	15.4	7.5	11.4	1.92	1.32	11.35	4.35	6.75	1.27	0.87	3.15	1.15	1.75	0.38	0.26	FR	39.4	8.2	13.4	4.19	2.88
P+Mj	S	26.8	12.6	16.4	4.42	3.04	14.5	6.10	8.35	1.12	0.77	2.80	1.50	1.90	0.25	0.17	FL	47.2	12.6	19.8	6.15	4.23
	R	16.5	7.7	11.2	1.85	1.27	10.45	4.15	6.20	1.05	0.72	2.55	1.00	1.40	0.39	0.27	FR	31.4	7.2	10.8	3.45	2.37
P+Rh+Mj	S	32.4	13.9	13.7	4.19	2.88	19.85	7.30	11.05	1.63	1.12	3.30	1.85	2.50	0.49	0.34	FL	67.4	16.4	27.2	5.44	3.74
	R	19.7	8.5	12.8	2.17	1.49	14.50	5.30	8.35	1.76	1.21	3.55	1.25	1.95	0.47	0.32	FR	49.2	10.4	16.4	5.22	3.59
L.S.D.																						
0.01	S	2.92	1.13	1.40			1.83	0.62	0.98			0.46	0.25	0.26			FL	7.80	1.58	1.98		
	R	1.62	0.79	1.32			1.66	0.60	0.70			0.30	0.19	0.21			FR	4.69	0.85	1.21		
0.05	S	2.14	0.83	1.03			1.34	0.46	0.72			0.34	0.18	0.19			FL	5.72	1.16	1.45		
	R	1.19	0.58	0.97			1.22	0.44	0.51			0.22	0.14	0.16			FR	3.44	0.62	0.89		

S = Shoot, R = Root

FL = Flower, FR = Fruit

Each value is mean of five replicates.

air pollution at both the sites, the effects being greater at K_1. At the unpolluted site, Rhizobium on lentil also reduced the root galling and eggmass production of M. incognita significantly. Rhizobium caused reduction in gall formation of M. javanica (significant at P = 0.05) but non-significantly in eggmass production. The suppressive effect of Rhizobium on root-knot disease was adversely affected by the ambient air pollution, being greater at K_1 than K_2. Root galling and eggmass production of the nematodes were lowest at the polluted sites, in the presence of Rhizobium (Table 7).

Root nodulation on lentil was also adversely affected by the ambient air pollution. The number of both total and functional nodules was significantly reduced at both the sites, the effect was greater at K_1. The inoculation of M. incognita and M. javanica adversely affected root nodulation at the unpolluted site. The number of total and functional nodules was significantly reduced. At the polluted sites, root nodulation was poorest when Rhizobium and root-knot nematodes were together. The number of nodules infected with root-knot nematodes was reduced by the ambient air pollution. At K_1, no nodule was found infected with root-knot nematode (Table 7).

Leaf pigments and seed proteins

Leaf pigment and seed protein contents of lentil

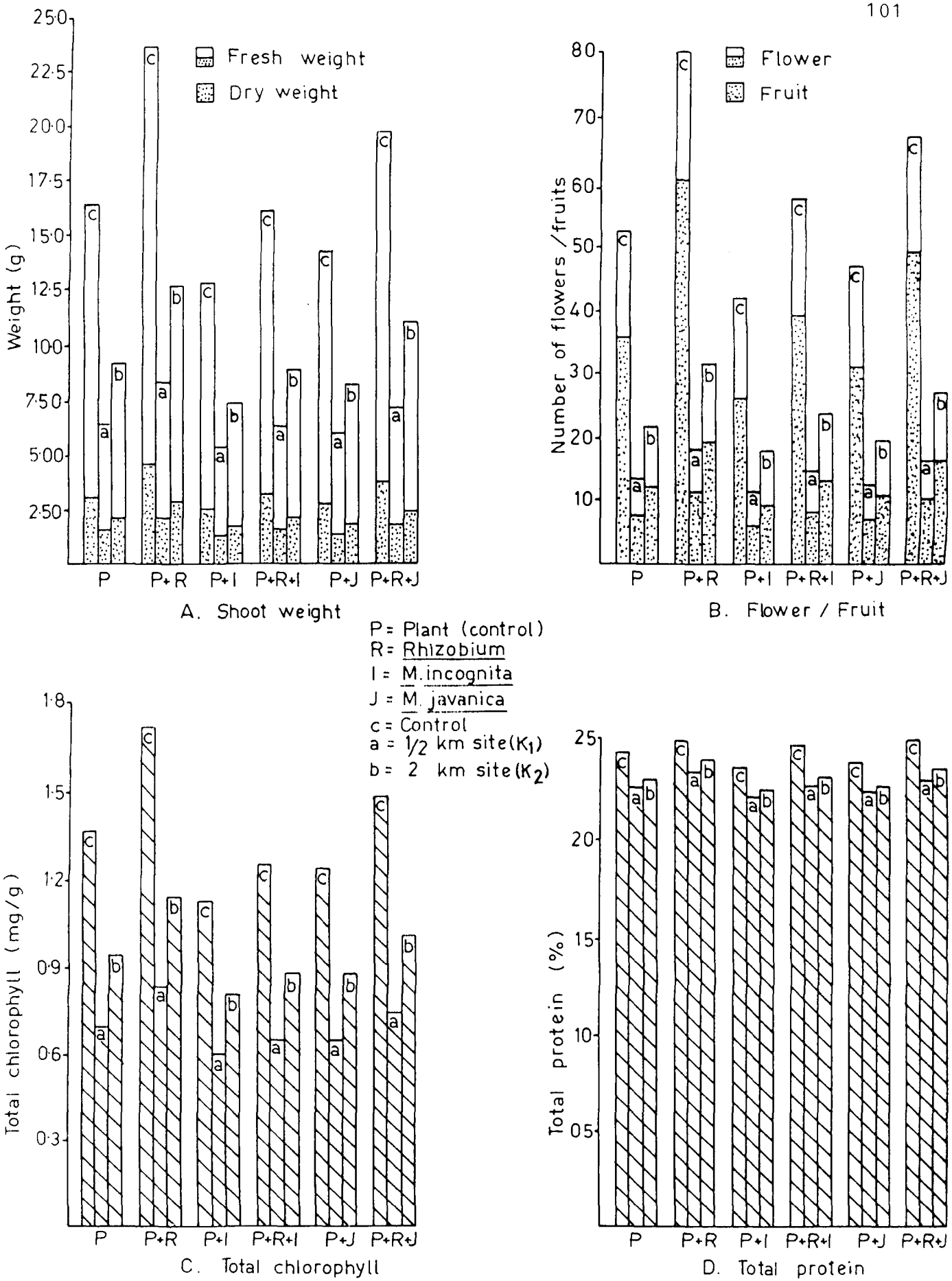

Fig.2. Interactive effects of ambient air pollution, root-knot nematodes and root nodule bacteria on some parameters of lentil.

were significantly and adversely affected by the ambient air pollution at both sites. Rhizobium significantly increased the leaf pigments and seed proteins in control plants. Both M. incognita and M. javanica reduced the chlorophyll and protein contents. The reduction was more due to M. incognita than M. javanica. Both M. incognita and M. javanica signi ficantly reduced the chlorophyll content. The reductions by M. incognita in soluble and total proteins were significant only at P = 0.05. M. javanica reduced insoluble protein significantly (P = 0.05) but the reductions in soluble and total proteins were not significant. M. incognita toge ther with Rhizobium also reduced chlorophyll content at the unpolluted site. The reductions in chlorophyll a and total chlorophyll were significant only at P = 0.05 while reduction in chlorophyll b was significant at P = 0.01. Conversely, Rhizobium in the presence of M. javanica increased the chloro- phyll content significantly (at P = 0.05) at the unpolluted site in comparison to control plants. In the presence of Rhizobium, adverse effects of both M. incognita and M. javanica on protein content of seeds were suppressed and instead an increase occurred. This increase due to M. incognita and Rhizobium was, however, not significant. M. javanica alonwith Rhizobium increased the soluble protein significantly at P = 0.01 and insoluble and total proteins at P = 0.05. The individual and combined effects of Rhizobium and M. incognita or M. javanica on leaf pigments and seed proteins were suppressed

Table 7. Interactive effects of ambient air pollution, root-knot nematodes and root nodule bacteria on root galling, eggmass production, leaf chlorophyll content and protein content of seeds of lentil.

		Gall/Eggmass					Nodule					Chlorophyll (mg/g)					Protein (%)				
					L.S.D.					L.S.D.					L.S.D.					L.S.D.	
		C	K_1	K_2	0.01	0.05	C	K_1	K_2	0.01	0.05	C	K_1	K_2	0.01	0.05	C	K_1	K_2	0.01	0.05
P (Control)												A 0.724	0.345	0.509	0.054	0.037	S 10.46	9.14	9.50	0.20	0.14
												B 0.563	0.298	0.405	0.057	0.039	I 13.94	13.44	13.52	0.19	0.13
												T 1.362	0.693	0.941	0.079	0.054	T 24.40	22.58	23.02	0.28	0.19
P+Rh							T 226.4	54.8	73.4	13.33	9.16	A 0.902	0.413	0.616	0.047	0.032	S 11.56	9.56	9.96	0.31	0.21
							F 203.2	38.2	56.6	15.04	10.34	B 0.714	0.352	0.488	0.060	0.041	I 15.28	13.82	14.10	0.28	0.19
												T 1.716	0.825	1.139	0.100	0.069	T 26.84	23.38	24.06	0.54	0.37
P+Mi	G	136.1	22.8	65.6	9.88	6.79						A 0.594	0.302	0.436	0.057	0.039	S 10.16	9.08	9.26	0.35	0.24
	E	93.2	9.6	17.6	4.77	3.28						B 0.457	0.259	0.346	0.052	0.036	I 13.52	13.16	13.26	0.25	0.17
												T 1.129	0.603	0.805	0.103	0.071	T 23.68	22.24	22.52	0.45	0.31
P+Rh+Mi	G	107.2	19.4	52.2	10.39	7.14	T 154.6	42.6	59.4	11.23	7.72	A 0.648	0.322	0.474	0.071	0.049	S 10.60	9.20	9.62	0.23	0.16
	E	70.6	7.4	14.7	4.96	3.41	F 110.4	27.4	41.0	9.95	6.84	B 0.496	0.276	0.377	0.061	0.042	I 14.02	13.44	13.58	0.28	0.19
							I 25.8	0.0	6.2	3.72	2.56	T 1.252	0.647	0.877	0.106	0.073	T 24.62	22.64	23.20	0.35	0.24
P+Mj	G	64.4	18.6	37.8	6.68	4.59						A 0.664	0.324	0.472	0.042	0.029	S 10.26	9.12	9.36	0.29	0.20
	E	37.8	10.2	14.2	3.94	2.71						B 0.503	0.277	0.375	0.045	0.031	I 13.66	13.28	13.32	0.26	0.18
												T 1.244	0.649	0.872	0.090	0.062	T 23.92	22.40	22.68	0.39	0.27
P+Rh+Mj	G	52.8	15.2	31.6	6.87	4.72	T 196.0	45.2	67.2	10.74	7.38	A 0.788	0.369	0.548	0.652	0.036	S 10.88	9.32	9.76	0.35	0.24
	E	34.2	6.2	11.4	4.13	2.84	F 151.4	31.6	48.8	11.77	8.09	B 0.523	0.316	0.434	0.065	0.045	I 14.24	13.64	13.82	0.19	0.13
							I 16.4	0.0	2.4	3.45	2.37	T 1.481	0.738	1.012	0.109	0.075	T 25.12	22.96	23.58	0.49	0.34
L.S.D.																					
0.01	G	12.24	1.78	5.44			T 23.77	4.67	7.20			A 0.079	0.053	0.056			S 0.40	0.29	0.26		
	E	7.89	0.94	1.91			F 24.08	3.68	5.60			B 0.059	0.029	0.065			I 0.34	0.38	0.42		
							I 4.10	0.00	1.01			T 0.139	0.098	0.113			T 0.85	0.59	0.55		
0.05	G	8.76	1.27	3.88			T 16.34	3.21	4.95			A 0.058	0.039	0.041			S 0.29	0.21	0.19		
	E	5.63	0.67	1.36			F 16.55	2.53	3.85			B 0.043	0.021	0.048			I 0.25	0.21	0.19		
							I 2.47	0.00	0.61			T 0.102	0.072	0.083			T 0.62	0.43	0.40		

G = Gall, E = Eggmass, T = Total, F = Functional, I = Infected; A = Chl.a, B = Chl.b, T = Total Chl.; S = Soluble, I = Insoluble, T = Total

Each value is mean of five replicates.

by the embient air pollution, the suppressions being greater at K_1 site (Table 7, Figs. 2C and 2D).

Leaf epidermal characters

The leaf epidermal characters of lentil were significantly and adversely affected by the ambient air pollution at both the sites, the effects being greater at K_1 than K_2. Inoculation of Rhizobium at the unpolluted site caused significant ($P = 0.01$) increase in stomatal count and size of stomata on both the leaf surfaces and stomatal aperture on upper leaf surface. The increase in size of stomatal aperture on lower surface was significant only at $P = 0.05$. Both M. incognita and M. javanica significantly reduced number and size of stomata and size of stomatal aperture at the unpolluted site. The adverse effects of M. incognita were greater than M. javanica. M. incognita even in the presence of Rhizobium significantly reduced the number of stomata on lower surface, size of stomatal aperture on upper surface, and size of stomata on both the surfaces. The reduction in the stomatal count on upper surface was not significant and the reduction in size of stomatal aperture on lower surface was significant only at $P = 0.05$. M. javanica alongwith Rhizobium increased the number of stomata and decreased the size of stomata and stomatal aperture, but these were not significant. The ambient air pollution suppressed the individual and combined effects

of all the three organisms on epidermal characters of lentil. The effect was greater at K_1 than K_2 (Table 8).

The ambient air pollution at both the polluted sites significantly increased the number and length of trichomes, the effects being greater at K_1. While Rhizobium inoculation at the unpolluted site significantly decreased the number and length of trichomes, both M. incognita and M. javanica increased their number and length. The effect of M. incognita in this respects was greater than M. javanica. The increases in length of trichomes on lower surface caused by M. incognita and on upper surface caused by M. javanica were, however, significant only at P = 0.05 and increase in length of trichomes on lower surface caused by M. javanica was not significant. M. incognita together Rhizobium non-significantly reduced the number of trichomes on both the surfaces and the length of trichomes on lower surface. The decrease in length of trichomes on upper surface was significant. M. javanica together with Rhizobium significantly decreased number and length of trichomes on both surfaces of leaves. The individual and combined effects of Rhizobium, M. incognita or M. javanica were suppressed by the ambient air pollution. The suppressive effects of the ambient air pollution was greater at K_1 than K_2 (Table 8).

Table 8. Interactive effects of ambient air pollution, root-knot nematodes and root nodule bacteria on some leaf epidermal characters of lentil.

Treatment		No. of stomata/cm^2			L.S.D.		Size of stomata (μm^2)			L.S.D.		Size of Stomatal aperture (μm^2)			L.S.D.	
		C	K_1	K_2	0.01	0.05	C	K_1	K_2	0.01	0.05	C	K_1	K_2	0.01	0.05
P (Control)	L	4936.83	3684.20	3887.27	347.24	238.67	660.44	550.37	574.30	58.41	36.71	86.44	75.15	79.30	6.34	4.36
	U	3538.06	2582.53	2472.68	272.27	187.14	591.12	484.52	503.51	33.42	22.97	69.15	58.90	62.30	4.20	2.89
P+Rh	L	5430.51	3978.94	4081.63	428.02	294.19	713.28	561.38	603.02	43.56	29.94	92.49	76.67	83.27	6.02	4.14
	U	3963.19	2763.31	2907.34	320.35	220.84	656.14	499.06	538.76	27.74	25.03	75.37	60.37	66.04	3.72	2.56
P+Mi	L	4485.03	3542.50	3632.96	439.29	301.94	582.91	517.27	529.86	37.06	25.47	77.18	72.28	73.43	6.10	4.19
	U	3173.15	2459.55	2539.52	370.58	254.71	517.62	447.09	461.93	47.17	32.42	60.66	55.36	56.43	3.87	2.66
P+Rh+Mi	L	4754.13	3648.78	3796.45	359.56	247.14	609.14	519.86	543.11	41.19	28.31	80.26	72.64	74.90	5.47	3.76
	U	3458.73	2570.23	2691.89	314.90	216.44	548.67	462.58	475.79	38.61	26.54	63.39	56.19	57.84	3.90	2.68
P+Mj	L	4613.86	3576.89	3702.16	395.49	271.83	594.98	519.21	531.76	43.15	29.66	78.56	72.49	74.60	5.95	4.09
	U	3251.89	2483.20	2587.43	379.45	260.81	527.79	455.38	464.49	40.88	28.10	61.74	56.53	58.28	3.99	2.74
P+Rh+Mj	L	5028.17	3755.74	3879.82	452.60	311.09	636.64	527.00	553.03	46.47	31.94	82.49	73.21	77.21	5.62	3.86
	U	3559.08	2632.19	2807.37	394.39	271.08	575.29	466.76	492.36	45.79	31.47	66.14	58.00	61.01	3.17	2.18
L.S.D.																
0.01	L	228.43	183.62	199.38			46.47	28.94	43.45			7.45	5.20	7.11		
	U	176.70	160.73	173.78			54.10	31.01	38.73			4.73	3.97	4.15		
0.05	L	167.49	134.63	146.19			34.07	21.22	31.86			5.46	3.81	5.21		
	U	129.56	117.85	127.42			39.67	22.74	28.40			3.47	2.91	3.04		

L = Lower surface, U = Upper surface.

Each value is mean of five replicates.

Table 8. (Cont nued)

		No. of trichomes/cm^2					Length of trichomes (µm)				
					L.S.D.					L.S.D.	
		C	K_1	K_2	0.01	0.05	C	K_1	K_2	0.01	0.05
P (Control)	L	2591.84	3524.90	3317.56	355.56	244.39	733.17	865.14	833.61	82.19	56.49
	U	1548.53	2136.97	2013.08	276.02	189.72	680.16	817.55	782.18	45.76	31.45
P+Rh	L	1963.52	2987.20	2654.05	322.14	221.42	591.26	779.41	703.47	92.85	63.82
	U	1082.87	1737.41	1548.52	314.85	216.41	507.58	704.78	620.82	48.13	33.08
P+Mi	L	2901.95	3665.89	3582.96	344.53	236.81	784.49	886.77	873.62	74.84	51.44
	U	1773.05	2250.23	2206.34	254.16	174.69	741.37	846.16	827.55	38.45	26.43
P+Rh+Mi	L	2545.63	3491.33	3257.24	370.59	254.72	694.23	844.54	801.49	72.50	49.83
	U	1453.42	2083.55	1902.01	271.25	186.44	633.65	790.81	738.91	43.05	29.59
P+Mj	L	2825.11	3595.40	3516.61	351.43	241.55	762.50	882.45	858.62	86.06	59.15
	U	1718.87	2201.08	2158.02	295.10	202.83	718.25	840.51	812.15	45.38	31.19
P+Rh+Mj	L	2242.15	3210.18	2930.51	402.75	276.82	630.17	802.22	740.19	69.28	47.62
	U	1282.74	1897.48	1740.34	307.11	211.09	552.56	730.82	659.44	50.51	34.72
L.S.D.											
0.01	L	122.99	163.06	171.46			56.04	50.08	58.81		
	U	169.49	118.07	141.04			40.11	28.74	33.91		
0.05	L	126.84	119.56	125.72			41.09	36.72	43.12		
	U	124.27	86.57	103.41			29.41	21.07	24.86		

L = Lower surface, U = Upper surface

Each value is mean of five replicates.

DISCUSSION

The ambient air pollution caused by the Thermal Power Plant, Kasimpur (coal fired) adversely affected the plant growth and yield of chick-pea and lentil at the both sites. The leaf pigments and seed proteins were reduced. The leaf epidermal characters were variously influenced. The favourable effects of Rhizobium and harmful effects of root-knot nematodes, M. incognita and M. javanica on plant growth, yield, leaf pigments and seed proteins were suppressed. Root nodulation by Rhizobium and root galling by the root-knot nematodes and their eggmass production were suppressed by the ambient air pollution. The effect in general was greater at the site K_1 than the site K_2, respectively, 1/2 and 2 km away from the stack. The results of the survey around the thermal power plant presented in the Section I showed that impacts of air pollution on considered parameters were greater in east-ward direction, indicating the greater level of pollution in the direction. The two sites in the present experiment were located in this direction (east-ward), though at different distances. The variation in the level of pollution between the two sites, observed in air pollution monitoring during the cropping season may be implicated as directly responsible for the differences in the effects of the ambient air pollution on various measures of the crops at the two sites. Since the levels of SO_2, NO_2, SPM and flyash deposition were

greater at K_1 (1/2 km distance), the effects were more on all the considered parameters.

The ambient air pollution caused reduction in the growth of both the crops. Appreciable reductions in growth parameters of plants caused by SO_2 and NO_2 have been found in various studies conducted in ambient or in artificial exposure conditions. The damaging effects of these gaseous air pollutants increase with the increasing concentration (Reinert, 1984; Olszyk and Thompson, 1985; Heck and MacLaughlin 1986; Heck et al. 1986; Leckowicz, 1987; Miller, 1987). SO_2, NO_2 and particulates are mainly produced by the use of fossil fuel in power plants (Wood, 1968; Carlson, 1983). The air pollution monitoring has shown that in the ambient level of pollution i.e. concentration of SO_2, NO_2, SPM and amount of flyash deposition was greater at K_1, the site closer to the point source. The variation in the concentrations of the air pollutants between the two sites (K_1 and K_2) was apparently caused by the difference in the distances of the sites from the point source. Distance from the point source, along with height of the stack, wind direction and speed and topography of the area are regarded as controlling factors of the concentration of air pollutants (Smith 1968; Thakre and Aggarwal, 1985).

The reduction in leaf pigment content (chlorophyll a chlorophyll b and total chlorophyll) of both chick-pea and lentil suggested interference of the air pollutants

in photosynthesis and synthesis of the pigments or caused their destruction. SO_2 and NO_2 are reported to reduce photosynthesis and chlorophyll content of leaves (Mudd and Kozlowski, 1975; Ziegler, 1975; Heath, 1980; Laurenroth and Dodd 1981,). They also induce some structural and chemical abnormalities in chloroplasts. The air pollutants after entry through stomata are converted into toxic forms which cause injury to leaf cells and chloroplasts. SO_2 also causes photo-oxidation of chlorophyll molecules (Nieboer et al. 1976), bleaching or phaeophytinization by degrading chlorophyll molecule to photosynthetically inactive form phaeophytin (Rao and LeBlanc, 1966, Varshney and Garg, 1979). This would reflect in photosynthetic activity of the affected plants. The deposition of particulate on the leaf surface reduce the light absorption area, that may affect the photosynthesis and add to the reduced growth and yield of the plants (Mark, 1963; Rao, 1971; Borka, 1980; Mishra and Shukla, 1986). This altered physiological and structural conditions, would ultimately lead to its poor growth and low chlorophyll content (Suwannapinunt and Kozlowsky, 1980; Irving and Miller, 1984). The reduction in protein content of seed might also be attributed to poor growth of the pollution stressed plants or direct interference of air pollutants or their transformed forms in the synthesis of proteins (Khan and Malhotra, 1983). The available literature on studies on air pollution effects

on leguminous and some other plants shows that the seed protein content is reduced by air pollution stress (Sprugel et al. 1980). Flowering and fruiting of chick-pea and lentil were also influenced by ambient air pollution. Flowering and fruiting including seed development are influenced by sub-lethal exposures to SO_2 (Varshney and Garg, 1979). Reductions in flowering and fruiting by air pollution have been observed in various plants (Amundson, 1983; Whitmore and Mansfield, 1983; Irving and Miller, 1984). Diminished pollen fertility and growth of pollen tube leading to failure of fertilization have been offered as possible causes for such a reduction. Poor plant growth might have also contributed towards the poor flowering and failure of fertilization resulting in reduced fruit setting (Linzon, 1978).

Since plant leaves remain in the direct contact of the air pollutants and gaseous air pollutants enter through stomata, alterations in stomatal features in air pollution stressed plant are natural. Air pollutants specially SO_2 induce opening of stomata and maximum damage occurs when stomata are open because of excessive loss of water through transpiration Varshney and Garg, 1979). Ambient air pollution stressed plants of chick-pea and lentil as a response showed reduction in number and size of stomata and size of stomatal aperture. This response was apparently structural adaptation of the leaves to reduce the intake

of gaseous air pollutants and loss of water. Similar response of leaves in relation to stomatal count and size and stomatal aperture have been observed (Majernik and Mansfield, 1970; Unsworth et al. 1972; Biscoe et al., 1973; Gupta and Ghouse, 1987a, 1987b). The stomatal conductance is also reduced in air pollution stressed plants (Bonte et al., 1977; Winner and Mooney, 1980; Kobriger et al., 1984). The number and size of trichome-hydathodes in chick-pea were reduced. Trichome-hydathodes by secreting aqueous solution, rich in minerals and carbohydrates, regulate the water pressure in leaves (Shneff, 1965; Fahn, 1982). Their reduction both in number and size was also a structural response of the leaves to reduced water pressure and relatively poor biochemical activities in ambient air pollution stressed dwarfed plants. Trichomes act as outer line of physical defence specially against the phytotoxic air pollutants and also regulate the transpiration rate. Increase in their number and length was to provide added protection to leaves in such a polluted environment. All the structural alterations in epidermal characters observed both in chick-pea and lentil were defensive responses to alleviate the adverse effects of air pollutants on various physiological and biochemical processes of the plants.

Seed germination and post-emergence mortality of seedlings of both the crops were influenced adversely at both the sites. The presence of air pollutants in the soil pore

spaces and toxic substances of flyash in the soils, might have affected the enzymatic activities during the various stages of germination (Horsman and Wellbrurn, 1977; Wyss and Brunold, 1980; Pierre and Queiroz, 1982). The post-emergence mortality of the seedlings was also correlated with the pollution concentration which demonstrated the direct involvement of air pollutants in their death. It is likely that all the seedlings at the tender age after the emergence could not resist the stress caused by the pollutants.

The beneficial effect of Rhizobium on the plant growth and yield of leguminous crops is well recognised. Rhizobium develops nodules on the root system and fixes atmospheric nitrogen to supply the plants. Rhizobium in return obtains carbohydrates from the plants. Presence of Rhizobium ensures better plant growth of legumes. Similar effects were noticed in plant growth response of chick-pea and lentil to Rhizobium inoculations. As a results of better plant growth and supply of nitrogen, leaf chlorophyll and seed protein contents increased in the plants at the unpolluted site. Improved plant growth influenced all the physiological and biochemical processes of the leguminous plants. The increased root growth might have enhanced water absorption, causing greater water pressure in leaves. As a response to this altered physiological condition, increase in the number and size of stomata, stomatal aperture size and number and length of trichome-hydathodes seemingly occurred. For the same reasons, trichome count

and length might have been reduced.

Root-knot nematodes, M. incognita and M. javanica caused growth and yield reductions both in chick-pea and lentil at the unpolluted site. They also reduced chlorophyll and protein contents. Epidermal characters were also influenced. M. incognita, and M. javanica attack a large number of crop plants and cause reduction in their growth and yield (Sasser, 1980; Sasser and Carter 1982). This reduction results from dysfunctioning of the absorption and supply system of water and minerals in infected plants because of various anatomical and biochemical changes induced by the nematodes. They obtain nutrients for their sustenance from the attacked plants and in turn plants suffer from various elemental deficiencies and show poor growth and yield (Masefield, 1958; Malek and Jenkins, 1964; Edongali and Perris, 1980). M. incognita and M. javanica are sedentary endoparasite and establish their host-parasite relationship through the formation of giant cells in the root tissues. They also deform and deshape xylem elements. Due to suppression of root growth and damage caused to the vascular system, absorption and conduction of absorbed water are impaired. The root knot diseased plants, therefore, show temporary wilting during the noon. Due to these reasons, the number and size of stomata and size of stomatal aperture and the number and length of trichome-hydathodes were possibly

reduced and the number and length of trichomes increased to check the water loss.

The root-knot nematodes and Rhizobium interacted antagonistically and as a result mutual inhibition of root galling and root nodulation occurred. M. incognita and M. javanica both were inhibitory for Rhizobium and root nodulation was suppressed in their presence. Similar results have been found by other workers on some legumes (Hussaini and Seshadri 1975; Bopaiah et al., 1976). The nutrient deficiency caused by the nematodes in host plants (Masefield, 1958; Malek and Jenkins, 1964), competition between the nematode juveniles and root nodule bacteria (Ichimohe, 1961; Epps and Chambers 1962; Malek and Jenkin, 1964) reduced translocation (Nutman, 1965), overall reduction of root system (Taha and Raski, 1969), secretion of some toxic substances by the nematodes (Moriarty, 1962; Wardojo et al., 1963; Bergeson, 1966; Doney et al., 1970) have been offered as possible reasons for such an affect of the nematode on root nodule bacteria. On the other hand, presence of Rhizobium adversely affected root galling and eggmass production of M. incognita and M. javanica on both chick-pea and lentil. In sequential inoculations, Hussaini and Seshadri, (1975) and Bopaiah et al. (1976) also observed reduced disease intensity caused by root-knot nematodes resulting from poor juvenile penetration. The chick-pea and lentil plants with improved vigour might have been more resistant for juvenile penetration

of the nematodes causing poor root galling. Anatagonistic interaction between the two organisms - Rhizobium (beneficial) and Meloidogyne (harmful) caused increase in plant growth in comparison to plants inoculated with Meloidogyne alone. Their interaction also reflected in other parameters considered in the study.

Rhizobium inoculation improved the plant growth and yield and increased the leaf chlorophyll and seed protein while the root-knot nematodes reduced their contents. M. incognita caused greater reductions than M. javanica because of the greater disease intensity, which indicated differential susceptibility of both chick-pea and lentil to the two different species of Meloidogyne. In most of the cases, M. incognita suppressed completely the beneficial effects of Rhizobium and exhibited adverse effects on various parameters, due to greater pathogenicity, while the adverse effects of M. javanica which were little in comparison to M. incognita, were overcome and masked by the beneficial effects of Rhizobium.

The root nodulation in both chick-pea and lentil were suppressed on plants grown in ambient air pollution. The direct toxic effects of the air pollutants on Rhizobium might have caused this suppression. Poor plant root growth might have indirectly aided it. In the controlled exposure studies, Reinert and Weber (1980) and Klarer et al., (1984) showed

that SO_2, SO_2+NO_2 reduced the number of bacterial nodules. The early death of the nodules might also be due to the toxic effects of the air pollutants. Researches have shown that both gaseous and particulate air pollutants adversely affect various soil microorganisms (Wong and Wong, 1980; Babich and Stotzky, 1982). The results of survey around the Thermal Power Plant, Kasimpur also showed the pollution induced inhibition of root nodulation, with a correlation with the pollution level (Section I).

The ambient air pollution also reduced the disease intensity caused by the nematodes, as observed in the survey (Section I). The reproduction of the nematodes also suffered. The inhibitory effect of air pollution on root-knot nematodes might have been caused either directly by reducing the root ingress of juveniles or indirectly through the host plants, which could not provide enough infection sites and support proper development of the nematodes because of its poor growth under the pollution stress. Consequently, less eggmasses were formed. The effect of the ambient air pollution showed a correlation with the pollution level because root galls and eggmasses were less at K_1 than K_2. Earlier studies have shown that the responses of nematodes to air pollutants are quite variable. Gaseous air pollutants either inhibit plant nematodes or enhance them, while some remain unaffected. O_3 and O_3-SO_2 mixture inhibited H. glycines and P. minor but B. longicaudatus remained unaffected. Foliar injury of begonia

caused by O_3 and O_3-SO_2 mixture also inhibited A. fragariae. Exposure of soybean plants to SO_2 enhanced the reproduction of P. penetrans in comparison to plants exposed to the charcoal filtered control air or O_3 (Weber et al., 1979). M. hapla has been shown to be favoured by O_3 - SO_2 mixture exposure on tobacco in the form of increased galling (Bisessar and Palmer, 1984).

In the present study, the ambient air pollution and the root-knot nematodes interacted antagonistically, in which root galling and eggmass production of both the nematodes on chick-pea and lentil were suppressed. In relation to plant growth, yield, leaf pigments and seed proteins, the antagonistic interaction of root-knot nematodes and ambient air pollution ameliorated the reductions caused by the nematodes. This was apparently due to inhibition of root-knot nematodes. In general the sum of the total of the reductions in plant growth, yield, leaf pigments and seed proteins caused by the ambient air pollution and root-knot nematodes (either species) individually was greater than the reductions caused by the combined effects of the ambient air pollution and either species of Meloidogyne. The interaction between the ambient air pollution and Rhizobium was also antagonistic, where root nodulation was greatly suppressed. Though the root nodulation was suppressed, the interactive effects of the ambient air pollution, root-knot nematodes and Rhizobium caused less reductions in parameters than the reductions caused by the ambient air pollution and root-knot nematodes in the absence of Rhizobium.

SUMMARY

Air pollution monitoring in the vicinity of the Thermal Power Plant, Kasimpur showed that air pollutants like SO_2, NO_2 and suspended particulate matter were present in the ambient air. Their concentration was greater at 1/2 km site (K_1) than 2 km site (K_2). Flyash desposition was also greater at K_1 than K_2.

The ambient air pollution adversely affected seed germination and survival of the seedlings of chick-pea and lentil. The suppression in seed germination and mortality of the seedling were greater at K_1 than K_2. The reduction in seed germination was greater in chick-pea than lentil while post-emergence of mortality of the seedlings was greater in lentil than chick-pea at both the polluted sites.

The ambient air pollution adversely affected plant growth (length, fresh and dry weights of shoot and root), flowering and fruiting, leaf pigments and seed proteins of chick-pea and lentil. The adverse effects of the ambient air pollution on all the considered parameters was consistently greater at K_1 than K_2.

Rhizobium promoted plant growth,yield,leaf pigment and seed protein contents of both the crops. These favourable effects of Rhizobium were reduced by the ambient air pollution. M. incognita and M. javanica caused the damaging effects on chick-pea and lentil

in relation to plant growth, yield, leaf pigments and seed proteins. These effects were reduced by the ambient air pollution. Rhizobium interacted antoginistically with the root-knot nematodes and reduced the damages caused by the nematodes. But the ambient air pollution suppressed the antagonistic interaction of Rhizobium with M. incognita or M. javanica, suppressing both the organisms. These effects of ambient air pollution were invariably greater at K_1. Root galling and eggmass production of M. incognita and M. javanica was adversely affected by the ambient air pollution on both the crops. Rhizobium also suppressed root-galling and eggmass production of both the species of Meloidogyne. Air pollution suppressed the adverse effect of Rhizobium on root-knot nematodes. The suppressive effect of the air pollution was greater at K_1 than K_2. The ambient air pollution also adversely affected root-nodulation by Rhizobium on both the crops. The suppression in root nodulation was greater at K_1 than K_2. Both the species of Meloidogyne also suppressed the root nodulation and infected some of the nodules. The suppressive effects of root-knot nematodes were reduced by the ambient air pollution, being greater at K_1.

Leaf epiderminal characters of both chick-pea and lentil responded variously to the ambient air pollution. The number of stomata and trichome-hydathodes and their dimensions, were adversely affected while number and length

of trichomes were increased. Rhizobium increased the number of stomata, size of stomata and stomatal aperture and number and length of trichome-hydathodes and decreased the number and length of trichomes. These effects of Rhizobium were suppressed by the ambient air pollution. The root-knot nematodes also decreased the number and size of stomata and stomatal aperture and trichome-hydathodes and increased the number and length of trichomes. The effects of M. incognita were greater than M. javanica. Rhizobium suppressed these effects of the root-knot nematodes when present together on the roots. The effects of both the species of Meloidogyne, separately and incombination with Rhizobium were suppressed by the ambient air pollution. The effect of ambient air pollution was invariably greater at K_1 than K_2.

SECTION III

INTERACTION OF $SO_2/O_3/SO_2$-O_3 MIXTURE, ROOT-KNOT NEMATODES AND ROOT NODULE BACTERIA ON CHICK-PEA AND LENTIL

Sulphur dioxide (SO_2) and nitrogen dioxide (NO_2) constitute major portion of the gaseous effluents produced during the burning of coal and mineral oil and smelting and refining of ores. NO_2 in the lower atmosphere converted into O_3 due to photolysis in the presence of hydrocarbons. The pollutants differ in their relative toxicity for plants. According to Reinert (1984) the order of their phytotoxicity is : O_3, SO_2 and NO_2. In the present study an attempt has been made to study the interaction of SO_2 and O_3 alone and in combination with root-knot nematodes and root nodule bacteria in artificial exposures and assess their interactive effects on plant growth, yield, leaf pigments, seed proteins, leaf epidermal characters and root-knot disease and root nodulation on chick-pea and lentil. Additionally, impact of SO_2, O_3 and SO_2+O_3 exposures on seed germination of chick-pea and lentil, in vitro growth of chick-pea and lentil strains of Rhizobium and juvenile hatching of the root-knot nematodes, M. incognita and M. javanica were also examined.

MATERIALS AND METHODS

Seed germination

To assess the impact of gaseous air pollutants (SO_2, O_3 and their mixture) on seed germination, seeds of chickpea (cv. T-3) and lentil (cv. T-36) were sown separately in seven sets of 30 cm clay pots (100 seeds/pot) containing sterilized sand. Pots were moistened with sterilized distilled water. Twenty four hours after sowing, the pots were exposed to SO_2 and O_3 singly, and in mixture (Table 1) for 4 hours in dynamic state exposure chambers (Standard Appliances, Varanasi). Each treatment was replicated five times.

The chambers were made up of transparent lucite sheet. The height of chambers was 120 cm and cross sectional areas was 8100 cm^2. The bottom plate of chambers was perforated. Perforation in the bottom plate in the form of nozzles and orifices provided smooth flow of thoroughly mixed air with pollutant(s) through the chambers. Air intake and circulation in the chamber was maintained by electric blower mounted under the bottom plate and controlled by an electronic regulator. Air entered in the chamber through the perforated base and passed out via an exhaust duct located at the top of the chamber.

The blower was provided with specific blades

for drawing air and maintaining a pressure drop at the suction end of the assembly. A ring shaped perforated tube was mounted at the suction side of blower through which gaseous pollutant(s) was dispensed. The gaseous pollutants(s) was instantly taken up, mixed with air and the mixture was continously pushed into the chambers through the nozzles and orifices provided in the bottom plate of chambers.

SO_2 was generated in a generator by the reaction of sodium sulphite and H_2SO_4 and O_3 was obtained by the UV ozone generator (Standard Appliances, Varanasi). Generators were connected with the blower of the chamber by a PVC tube. The different concentrations of SO_2 and O_3 were obtained by changing the amount of air intake in the exposure chambers. For studying the effect of single pollutant (SO_2 or O_3) the generators were connected separately with the exposure chambers. The mixture of both SO_2 and O_3 was obtained by connecting both the generators in one exposure chamber .

For determining the concentration of air pollutants during the exposure period, sampling were done by air sampler (Kimoto, Japan) and analysed in laboratory. The concentration of SO_2 and O_3, in the sampled air were determined by Weast and Fack method and Alkaline KI method respectively as prescribed by National Environmental Engineering Research

Institute, Nagpur in its Air Quality Monitoring Course Manual (Anon., 1986).

The following treatments of gases were considered for the exposure -

1 = Unexposed (control)

2 = SO_2 (0.1 ppm)

3 = SO_2 (0.2 ppm)

4 = O_3 (0.1 ppm)

5 = O_3 (0.2 ppm)

6 = SO_2 + O_3 (0.1+0.1 ppm)

7 = SO_2 + O_3 (0.2+0.2 ppm)

After 4 days of the first exposure , pots were again exposed to the same dosage of the pollutants.

In all the treatments including the control, successfully germinated seeds and the seedlings which died after emergence were counted after ten days of sowing. During the study period the pots were moistened regularly.

Growth of Rhizobium

Chick-pea and lentil strains of Rhizobium were grown separately in seven sets of 10 cm petriplates containing 25 ml YMA with five replications. Six sets of the petriplates were exposed twice for 4 h in one time exposure to SO_2 and O_3 alone and in mixture treatments as considered

for seed germination. First exposure was given one day after inoculation and later 4 days after the first exposure, for 4 h in micro-exposure chamber (Standard Appliances, Varanasi) in aseptic condition. The micro-exposure chambers were kept in the exposure chambers. The pollutants were generated and their concentrations were maintained in the exposure chambers as done for seed germination. Air and pollutant(s) mixtures of desired concentration maintained in exposure chamber was passed through air sterilization unit fitted with filter. The sterilization unit was attached with micro-exposure chamber.

Exposed and unexposed (control) petriplates were incubated at $28\pm2^{\circ}C$ in an incubator. After ten days of incubation of the petriplates, radial growth of Rhizobium colonies was measured.

Juvenile hatching

To assess the impact of the pollutants considered in the study on the juvenile hatching of M. incognita and M. javanica, 50 eggmasses of almost equal size of each species were kept in 7 cm paper cups containing sterilized sand and cups were than moistened with sterilized distilled water. The cups were divided into 7 sets having five replicates. Each set of cups exposed twice to the various doses of air pollutants as done in case of seed germination.

The cups were kept in glasshouse before and after exposure to pollutants. After 10 days, the hatched juveniles from each treatment were isolated and collected over 500 mesh sieve and counted. The sand in cups was moistened regularly during the study period.

Interaction studies

To study the interaction of $SO_2/O_3/SO_2+O_3$, root-knot nematodes and root-nodule bacteria on chick-pea (cv. T-3) and lentil (cv. T-36), the plant culture and the inoculations of Rhizobium and M. incognita and M. javanica were done as described in the section II. The pollutant exposures as considered for seed germination were given to each set of pots for 4 h at one time exposure, twice a week till the termination of the experiment since the start of exposure.

The exposures of plants to various air pollutants were started at three different times in relation to nematode inoculation as given below:

(i) Exposure I (Pre-inoculation exposure)

Exposure started one week before nematode inoculation.

(ii) Exposure II (Simultaneous inoculation exposure)

Exposure started at the time of nematode inoculation.

(iii) Exposure III (Post-inoculation exposure)

Exposure started after one week of nematode inoculation.

During the study period the pots were kept in glass-house under the unpolluted air after exposure to the pollutants.

After 100 days of sowing, the experiment was terminated and all the parameters considered for the study were determined as described in the section II.

RESULTS

Seed germination

Seed germination of both chick-pea and lentil were variously suppressed by SO_2 and O_3 individually and by their mixtures. The adverse effects of 0.2 ppm of SO_2 and O_3 acting alone and of their mixture (SO_2+O_3, 0.2 ppm each) were greater than the 0.1 ppm of the pollutants. SO_2 at 0.1 ppm, however, did not suppress seed germination of lentil. The post-emergence mortality of seedlings of both chick-pea and lentil was increased due to pollutant exposures. O_3 was more effective than SO_2 at both the concentrations in these respects. The reduction in seed germination of chick-pea was greater than lentil while the post-emergence mortality of seedlings was greater in lentil than chick-pea due to the pollutant exposures. The mixtures of SO_2 and O_3 at both the concentrations were more effective than the pollutants acting individually (Table 1).

Table 1. Effect of SO_2, O_3 and SO_2-O_3 mixtures on seed germination of chick-pea and lentil.

Pollutant ppm	Chick-pea			Lentil		
	Germination %	Reduction over control %	Seedling mortality %	Germination %	Reduction over control %	Seedling mortality %
Control	93		1	87		2
SO_2(0.1)	91	2.15	8	87	0.00	11
SO_2(0.2)	81	12.90	16	79	9.20	20
O_3(0.1)	86	7.53	11	81	6.90	13
O_3(0.2)	74	20.43	20	74	14.94	25
SO_2+O_3(0.1+0.1)	81	12.90	14	80	8.05	15
SO_2+O_3 (0.2+0.2)	72	22.58	23	71	18.39	29

Growth of Rhizobium

In vitro growth of chick-pea and lentil strains of Rhizobium was suppressed by SO_2, O_3 and SO_2-O_3 mixtures. The per cent reductions obtained in growth of chick-pea and lentil strains of Rhizobium by various treatments are reported in Table 2. Both SO_2 and O_3 were more effective at 0.2 ppm than 0.1 ppm in suppressing the growth. SO_2 at both

Table 2. Effect of SO_2, O_3 and SO_2 - O_3 mixtures on growth of chick-pea and lentil strains of Rhizobium in vitro.

Pollutant ppm	Chick-pea strain		Lentil strain	
	Colony growth (radia) mm	Reduction over control %	Colony growth (radial) mm	Reduction over control %
Control	7.4		13.6	
SO_2(0.1)	5.6	24.32	10.9	19.85
SO_2(0.2)	5.3	28.38	10.2	25.00
O_3(0.1)	5.8	21.62	10.3	24.26
O_3(0.2)	5.3	28.38	9.4	30.88
SO_2+O_3(0.1+0.1)	4.5	39.19	8.7	36.03
SO_2+O_3(0.2+0.2)	3.5	52.70	6.8	50.00

the concentrations, was more suppressive for chick-pea strain than lentil strain. O_3, on the other hand at both concentrations was more effective in suppressing the growth of lentil strain than chick-pea strain. The mixture of the gases at both the concentrations caused greater reductions in growth than their individual exposures.

Juvenile hatching

Juvenile hatching of both M. incognita and M. javanica was adversely affected by SO_2, O_3 and the mixtures of SO_2 and O_3. The effects on juvenile hatching are given in Table 3.

Table 3. Effect of SO_2, O_3 and SO_2 - O_3 mixtures on juvenile hatching of Meloidogyne incognita and M. javanica.

Pollutant ppm	M. incognita		M. javanica	
	Juvenile/ eggmass	Reduction over control %	Juvenile/ eggmass	Reduction over control %
Control	285		263	
SO_2(0.1)	275	3.51	257	2.28
SO_2(0.2)	253	11.23	236	10.27
O_3(0.1)	261	8.42	249	5.32
O_3(0.2)	196	31.23	192	27.00
SO_2+O_3 (0.1+0.1)	221	22.46	217	17.49
SO_2+O_3 (0.2+0.2)	155	45.61	156	40.68

The effects were related to the air pollutant(s) involved and the concentration used in exposures. O_3 at both the concentrations was comparatively more inhibitory than SO_2. The higher concentration (0.2 ppm) of each gas or their mixture caused inhibition than their lower concentration (0.1 ppm). The mixtures of the gases at both the concentrations caused greater inhibitory effect. All the exposures were more inhibitory for M. incognita than M. javanica, regardless of kind or concentration of the air pollutant (Table 3).

CHICK-PEA, Cicer arietinum L.

SULPHUR DIOXIDE (SO_2)

Plant growth and yield

In general SO_2 caused significant reductions in plant growth (length, fresh and dry weights of shoot and root) and yield characters (number of flowers and fruits/plant) of chick-pea. The reductions caused by 0.2 ppm SO_2 were greater than 0.1 ppm. When Rhizobium was inoculated, it significantly increased plant growth and yield characters in comparison to plants without Rhizobium. When Rhizobium inoculated plants were exposed to either concentration of SO_2, plant growth and yield were reduced. But plant growth and yield were greater than the plants without Rhizobium, exposed to respective concentration of SO_2. Both M. incognita and M. javanica reduced the plant growth and yield. When plants inoculated with either species of Meloidogyne were exposed, plant growth and yield reduced in comparison to unexposed plants with nematodes and the exposed plants without nematodes. In the presence of Rhizobium all the growth and yield parameters were also reduced by M. incognita except dry weight of shoot which, however, showed significant increase. M. javanica in the presence of Rhizobium did not cause significant reductions in plant growth and yield. Insted increase occurred in

Table 4 . Interactive effects of SO_2, root-knot nematodes and root nodule bacteria on plant length and fresh weight of chick-pea.

Treatment		Length (cm)									Fresh weight (g)								
			0.1 ppm			0.2 ppm			L.S.D.			0.1 ppm			0.2 ppm			L.S.D.	
		C	Pe	S	Pt	Pe	S	Pt	0.01	0.05	C	Pe	S	Pt	Pe	S	Pt	0.01	0.05
P (Control)	S	32.6	26.8	26.9	26.9	23.6	23.7	23.7	3.37	2.49	25.25	20.90	20.95	20.95	17.80	17.80	17.85	2.48	1.83
	R	22.7	18.9	18.9	19.0	17.2	17.3	17.3	2.36	1.74	17.50	14.10	14.10	14.10	12.70	12.70	12.70	1.99	1.47
P+Rh	S	42.4	33.0	33.1	33.1	28.2	28.1	28.3	3.74	2.76	38.25	28.85	28.90	28.90	22.05	22.05	22.10	2.86	2.11
	R	27.5	22.7	22.8	22.8	20.3	20.3	20.3	2.60	1.92	24.25	17.95	17.90	17.90	15.05	15.10	15.10	2.62	1.93
P+Mi	S	25.2	21.5	21.8	21.2	19.3	19.6	18.9	3.05	2.25	21.85	18.55	18.85	18.40	16.15	16.45	16.00	2.52	1.86
	R	16.4	14.8	15.2	14.6	13.9	14.2	13.6	1.57	1.16	14.80	12.05	12.25	11.95	11.15	11.35	11.05	1.50	1.11
P+Rh+Mi	S	30.7	24.7	25.8	24.1	21.6	22.8	21.3	4.16	3.04	30.10	23.55	24.55	22.95	19.05	19.75	18.75	2.78	2.05
	R	19.6	16.7	17.6	16.2	15.4	16.0	14.7	2.34	1.73	18.30	14.35	14.95	13.95	12.15	12.60	11.95	1.88	1.39
P+Mj	S	29.3	25.5	25.6	25.3	22.5	22.6	22.4	3.84	2.83	24.15	20.05	20.15	19.95	17.10	17.20	17.05	2.29	1.69
	R	19.8	17.2	17.6	17.1	16.1	16.3	15.9	1.98	1.46	16.75	13.50	13.55	13.45	12.25	12.35	12.20	2.11	1.56
P+Rh+Mj	S	36.4	29.8	31.0	29.4	25.9	26.7	25.6	3.51	2.59	34.15	26.75	27.40	26.25	20.35	20.80	20.10	2.51	1.85
	R	23.9	19.8	20.7	19.3	17.9	18.8	17.5	2.05	1.51	21.85	16.45	16.95	16.25	13.60	13.95	13.45	2.33	1.72
L.S.D.																			
0.01	S	3.72	3.07	3.16	3.01	2.92	2.88	2.84			2.03	1.75	1.79	1.66	1.53	1.46	1.55		
	R	1.73	1.51	1.46	1.49	1.40	1.42	1.38			1.55	1.46	1.49	1.42	1.39	1.34	1.45		
0.05	S	2.73	2.25	2.32	2.21	2.14	2.11	2.08			1.49	1.28	1.31	1.22	1.12	1.07	1.14		
	R	1.27	1.11	1.07	1.09	1.02	1.04	1.01			1.14	1.07	1.09	1.04	1.02	0.98	1.06		

C = Control, Pe = Pre-inoculation, S = Simultaneous inoculation, Pt = Post-inoculation, P = Plant, Rh = *Rhizobium*, Mi = *Meloidogyne incognita* Mj = *M. javanica* (These abbreviations are common to all subsequent tables).

S = Shoot, R = Root. Each value is mean of five replicates.

Table 5. Interactive effects of SO_2, root-knot nematodes and root nodule bacteria on plant dry weight, flowering and fruiting of chick-pea.

Treatment		Dry weight (g)									Flower/Fruit								
			0.1 ppm			0.2 ppm			L.S.D.			0.1 ppm			0.2 ppm			L.S.D.	
		C	Pe	S	Pt	Pe	S	Pt	0.01	0.05	C	Pe	S	Pt	Pe	S	Pt	0.01	0.05
P (Control)	S	5.80	4.90	4.90	4.95	4.25	4.30	4.30	0.69	0.51	FL 96.8	64.6	64.8	64.8	59.2	59.2	59.4	7.16	5.28
	R	4.15	3.40	3.40	3.45	3.10	3.15	3.15	0.47	0.35	FR 64.6	42.6	42.6	42.8	38.6	38.8	38.8	5.08	3.75
P+Rh	S	8.95	6.95	6.95	6.90	5.45	5.45	5.50	1.02	0.75	FL 150.4	80.4	80.4	80.6	67.4	67.6	67.6	10.11	7.46
	R	5.75	4.45	4.45	4.45	3.90	3.90	3.95	0.65	0.48	FR 110.2	60.6	60.8	60.8	50.6	50.6	50.8	7.97	5.88
P+M1	S	5.10	4.35	4.45	4.35	3.90	3.95	3.85	0.57	0.42	FL 58.8	41.0	42.4	40.2	38.4	39.8	37.6	5.81	4.29
	R	3.45	2.90	2.95	2.90	2.75	2.80	2.70	0.43	0.32	FR 35.8	25.8	27.4	25.2	24.4	25.4	23.8	3.10	2.29
P+Rh+M1	S	7.20	5.60	5.48	4.45	5.00	4.80	4.55	0.79	0.58	FL 70.2	47.2	49.8	45.4	41.6	45.8	40.8	7.68	5.67
	R	4.00	3.50	3.65	3.40	3.05	3.15	3.00	0.38	0.28	FR 45.4	30.4	33.6	29.2	28.2	30.2	26.6	5.04	3.72
P+Mj	S	5.45	4.70	4.75	4.70	4.10	4.15	4.10	0.51	0.38	FL 70.4	49.4	51.0	48.6	46.6	48.2	45.8	6.57	4.85
	R	3.38	3.25	3.25	3.25	3.00	3.05	3.00	0.50	0.37	FR 48.0	34.4	35.2	33.8	32.8	33.2	31.8	4.43	3.27
P+Rh+Mj	S	8.15	6.40	6.55	6.30	5.05	5.10	4.95	0.84	0.62	FL 98.2	57.8	61.2	56.0	51.4	54.2	50.2	5.08	3.75
	R	4.90	4.05	4.20	4.00	3.45	3.55	3.40	0.35	0.36	FR 67.2	43.0	45.8	40.8	38.8	43.4	36.8	5.57	4.11
L.S.D. 0.01	S	0.94	0.57	0.55	0.49	0.46	0.42	0.41			FL 6.30	5.62	5.48	5.59	4.47	4.71	4.95		
	R	0.63	0.49	0.44	0.48	0.38	0.40	0.33			FR 5.40	4.71	4.81	4.62	3.90	3.75	3.66		
0.05	S	0.69	0.42	0.40	0.36	0.34	0.31	0.30			FL 4.62	4.12	4.02	4.10	3.28	3.45	3.63		
	R	0.46	0.36	0.32	0.35	0.28	0.29	0.24			FR 3.96	3.45	3.53	3.39	2.86	2.75	2.68		

S = Shoot, R = Root,

FL = Flower, FR = Fruit

Each value is mean of five replicates.

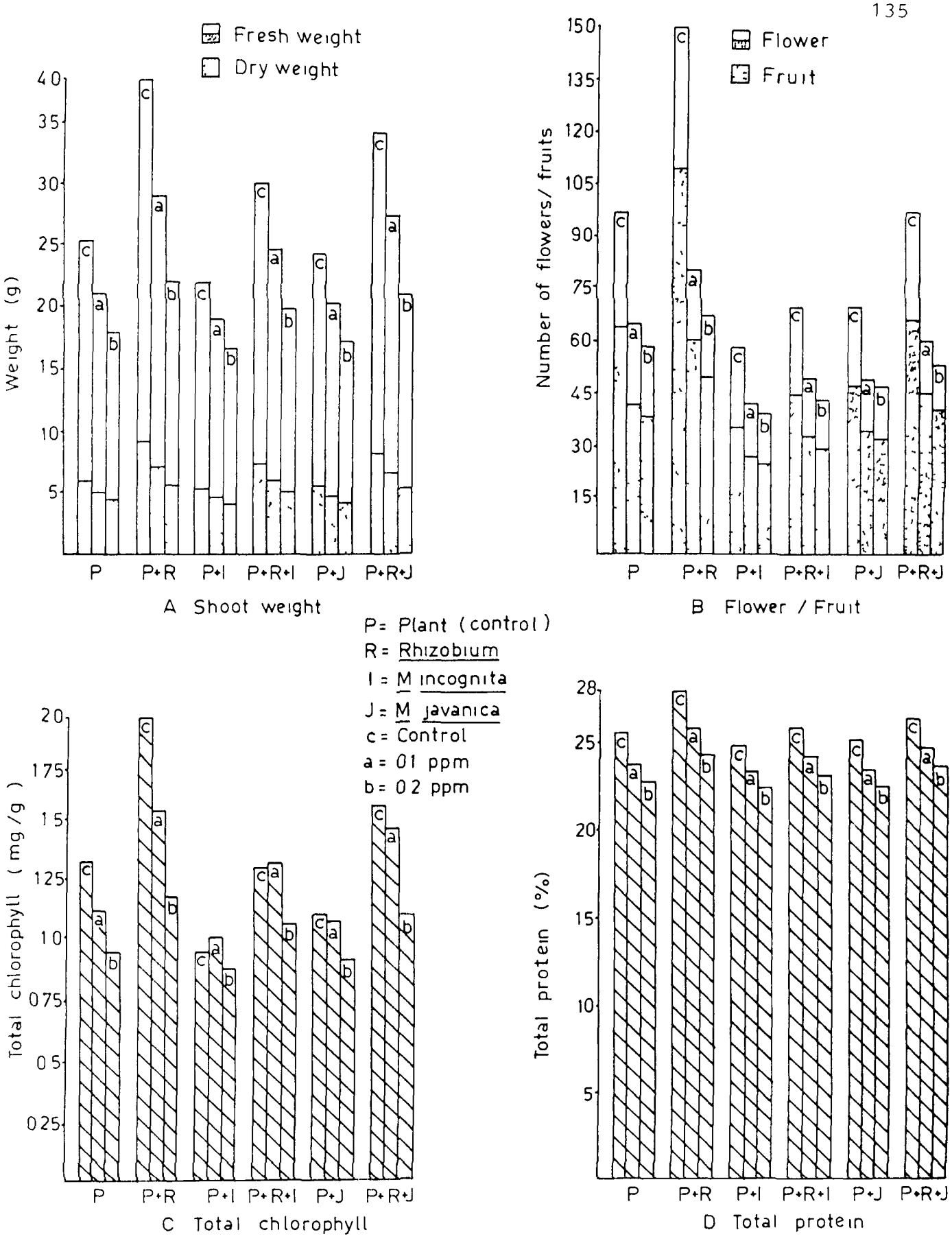

Fig 1 Interactive effects of SO_2 root-knot nematodes and root nodule bacteria on some parameters of chick-pea in simultaneous inoculation exposure

all the growth and yield parameters. When plants inoculated with Rhizobium and either species of Meloidogyne were exposed to SO_2 concentrations, plant growth and yield decreased in comparison to plants inoculated with Rhizobium alone or with Rhizobium and M. incognita or M. javanica or Rhizobium inoculated exposed plants. Plant growth and yield parameters were highest in simultaneous inoculation exposures and lowest in post-inoculation exposures (Tables 4 and 5, Figs. 1A and 1B)

Root-knot disease and root nodulation

SO_2 significantly reduced root-galling and eggmass production of both M. incognita and M. javanica. Suppressive effect of 0.2 ppm SO_2 was greater than 0.1 ppm. Root galling and eggmass production of M. incognita and M. javanica were also inhibited by Rhizobium. Root galling and eggmass production of the nematodes were further suppressed by the exposures in the presence of Rhizobium. Root-galling and eggmass production of both the species were highest in post-inoculation exposures and lowest in simultaneous inoculation exposures. The same trend was noticed even in the presence of Rhizobium (Table 6).

Root nodulation was significantly suppressed by the SO_2 exposures (0.1 ppm and 0.2 ppm). The suppressive effect of 0.2 ppm SO_2 was greater than 0.1 ppm. Root nodulation

Table 6. Interactive effects of SO_2, root-knot nematodes and root nodule bacteria on root galling, eggmass production and root nodulation on chick-pea.

Treatment		Gall/Eggmass									Nodule								
			0.1 ppm			0.2 ppm			L.S.D.			0.1 ppm			0.2 ppm			L.S.D.	
		C	Pe	S	Pt	Pe	S	Pt	0.01	0.05	C	Pe	S	Pt	Pe	S	Pt	0.01	0.05
P																			
P+Rh											T 140.4	113.2	113.2	113.6	101.4	101.8	102.0	11.71	8.64
											F 120.6	89.2	89.2	89.4	76.8	76.8	77.2	9.77	7.21
											I -	-	-	-	-	-	-	-	-
P+Mi	G	176.2	156.2	128.4	163.4	127.8	104.2	133.4	10.69	7.89									
	E	108.6	67.4	54.2	70.8	45.2	36.8	45.4	7.90	5.83									
P+Rh+Mi	G	125.6	113.4	93.2	119.6	92.4	76.8	97.2	8.47	6.25	T 100.2	74.6	82.2	70.6	69.2	72.4	66.2	8.93	6.59
	E	86.4	48.0	39.4	51.2	32.8	26.6	34.6	6.37	4.70	F 70.8	54.4	62.2	50.8	48.2	52.8	45.6	7.98	5.89
											I 15.2	11.8	9.2	10.2	9.6	8.4	9.0	1.69	1.25
P+Mj	G	83.4	76.4	62.2	78.0	64.6	52.4	66.2	5.65	4.17									
	E	48.6	34.6	28.2	25.4	24.2	20.4	25.2	4.36	3.22									
P+Rh+Mj	G	52.2	48.4	40.8	50.2	40.2	35.4	42.6	4.26	3.14	T 125.4	87.2	94.2	84.4	78.6	82.0	76.2	9.16	6.76
	E	33.8	22.4	19.6	21.2	16.4	13.2	16.6	4.16	3.07	F 100.6	65.6	72.4	62.6	56.4	61.2	54.0	8.24	6.08
											I 11.2	9.2	6.2	7.8	6.4	4.6	5.2	1.03	0.76
L.S.D.																			
0.01	G	8.05	6.90	6.81	7.04	5.64	5.41	5.54			T 18.46	9.56	9.22	10.01	8.32	7.81	8.26		
	E	7.40	5.40	5.51	5.27	3.67	3.52	3.49			F 13.30	8.98	7.67	8.13	6.20	6.31	6.10		
											I 3.17	1.44	1.21	1.13	1.16	1.24	1.11		
0.05	G	5.74	4.92	4.86	5.02	4.02	3.86	3.95			T 12.69	6.57	6.34	6.88	5.72	5.37	5.68		
	E	5.28	3.85	3.93	3.76	2.62	2.51	2.49			F 9.14	6.17	5.27	5.59	4.26	4.34	4.19		
											I 1.91	0.87	0.73	0.68	0.70	0.75	0.67		

G = Gall, E = Eggmass

T = Total, F = Functional, I = Infected

Each value is mean of five replicates.

was also suppressed by the root-knot nematodes. Root nodulation was further suppressed when the plants inoculated with Rhizobium and either species of root-knot nematode were exposed to SO_2. The number of total, functional and infected nodules was reduced by SO_2 exposures in comparison to the unexposed plants with Rhizobium and root-knot nematode. The number of total and functional nodules were smaller than exposed plants inoculated with Rhizobium alone. The number of total and functional nodules was greatest in simultaneous inoculation exposures and smallest in post-inoculation exposures. The number of nodules infected with the nematodes was highest in pre-inoculation exposures and lowest in simultaneous inoculation exposures (Table 6).

Leaf pigments and seed proteins

Leaf pigments (chlorophyll a, chlorophyll b and total chlorophyll) and seed proteins (soluble, insoluble and total protein) were significantly reduced by the SO_2 exposures of the plants. Reductions were greater by 0.2 ppm than 0.1 ppm. When Rhizobium inoculated plants were exposed, leaf pigments and seed proteins were greater than exposed plants without Rhizobium and were smaller than the unexposed plants with Rhizobium. Both M. incognita and M. javanica reduced the leaf pigments significantly at 0.1 ppm and seed proteins non-significantly. When the plants inoculated with root-knot nematode (either species) were exposed,

Table 7. Interactive effects of SO_2, root-knot nematodes and root nodule bacteria on chlorophyll content of leaves and protein content of seeds of chick-pea.

Treatment		Chlorophyll (mg/g) C	0.1 ppm Pe	0.1 ppm S	0.1 ppm Pt	0.2 ppm Pe	0.2 ppm S	0.2 ppm Pt	L.S.D. 0.01	L.S.D. 0.05		Protein (%) C	0.1 ppm Pe	0.1 ppm S	0.1 ppm Pt	0.2 ppm Pe	0.2 ppm S	0.2 ppm Pt	L.S.D. 0.01	L.S.D. 0.05
P (Control)	A	0.621	0.525	0.525	0.527	0.447	0.447	0.449	0.061	0.045	S	11.30	10.20	10.20	10.26	9.28	9.28	9.30	0.49	0.36
	B	0.571	0.474	0.474	0.478	0.402	0.402	0.403	0.053	0.039	I	14.36	13.62	13.64	13.66	13.54	13.56	13.60	0.56	0.41
	T	1.313	1.110	1.110	1.113	0.945	0.945	0.948	0.115	0.085	T	25.66	23.82	23.86	23.92	22.82	22.84	22.90	1.02	0.75
P+Rh	A	0.943	0.720	0.721	0.721	0.552	0.549	0.552	0.098	0.072	S	12.34	11.00	11.04	11.06	9.84	9.88	9.92	0.39	0.29
	B	0.878	0.651	0.654	0.656	0.498	0.495	0.498	0.095	0.070	I	15.62	14.70	14.72	14.74	14.42	14.44	14.48	0.65	0.48
	T	1.901	1.522	1.524	1.526	1.167	1.165	1.167	0.157	0.116	T	27.96	25.70	25.76	24.80	24.26	24.32	24.40	1.53	1.13
P+Mi	A	0.447	0.466	0.474	0.462	0.407	0.415	0.404	0.028	0.021	S	10.94	9.90	10.02	9.86	9.06	9.12	9.02	0.57	0.42
	B	0.412	0.419	0.427	0.416	0.365	0.372	0.362	0.033	0.024	I	13.96	13.26	13.38	13.22	13.22	13.32	13.18	0.46	0.34
	T	0.945	0.965	1.002	0.976	0.861	0.876	0.853	0.066	0.049	T	24.90	23.16	23.40	23.08	22.28	22.44	22.20	1.07	0.79
P+Rh+Mi	A	0.612	0.589	0.613	0.575	0.479	0.496	0.471	0.043	0.032	S	11.40	10.24	10.32	10.18	9.32	9.40	9.30	0.46	0.34
	B	0.559	0.533	0.555	0.520	0.432	0.447	0.424	0.039	0.029	I	14.38	13.70	13.82	13.66	13.62	13.70	13.58	0.50	0.37
	T	1.285	1.245	1.297	1.215	1.012	0.048	0.995	0.070	0.052	T	25.78	23.94	24.14	23.84	22.94	23.10	22.88	0.98	0.72
P+Mj	A	0.520	0.502	0.505	0.500	0.430	0.432	0.429	0.027	0.020	S	11.10	10.04	10.06	9.96	9.14	9.20	9.12	0.66	0.49
	B	0.479	0.453	0.456	0.451	0.387	0.388	0.385	0.023	0.071	I	14.06	13.34	13.40	13.36	13.36	13.46	13.34	0.72	0.53
	T	1.094	1.062	1.068	1.038	0.909	0.914	0.907	0.056	0.041	T	25.16	23.38	23.46	23.32	22.50	22.66	22.46	1.38	1.02
P+Rh+Mj	A	0.729	0.670	0.683	0.648	0.510	0.521	0.504	0.045	0.033	S	11.68	10.52	10.58	10.48	9.56	9.60	9.54	0.45	0.33
	B	0.660	0.607	0.620	0.587	0.460	0.470	0.455	0.039	0.029	I	14.72	14.04	14.14	14.00	13.96	14.02	13.92	0.61	0.45
	T	1.539	1.516	1.445	1.370	1.060	1.101	1.067	0.084	0.062	T	26.40	24.56	24.72	24.48	23.52	23.62	23.46	1.26	0.93
L.S.D.																				
0.01	A	0.060	0.053	0.050	0.049	0.045	0.044	0.048			S	0.65	0.46	0.44	0.44	0.38	0.41	0.35		
	B	0.057	0.049	0.052	0.046	0.042	0.046	0.044			I	0.65	0.55	0.49	0.53	0.42	0.38	0.40		
	T	0.106	0.094	0.100	0.093	0.079	0.082	0.097			T	0.97	0.89	0.90	0.86	0.70	0.65	0.61		
0.05	A	0.044	0.039	0.047	0.036	0.033	0.032	0.035			S	0.48	0.34	0.32	0.32	0.28	0.30	0.26		
	B	0.042	0.036	0.038	0.034	0.031	0.034	0.032			I	0.46	0.40	0.36	0.39	0.31	0.28	0.29		
	T	0.078	0.069	0.073	0.068	0.058	0.060	0.071			T	0.71	0.65	0.66	0.63	0.51	0.48	0.45		

A = Chl.a, B= Chl.b, T = Total chl.

S = Soluble, I = Insoluble, T = Total

Each value is mean of five replicates.

leaf pigments and seed proteins were reduced and were less than the exposed plants without nematode or unexposed plants inoculated with root-knot nematode (either species). Loss in leaf pigments and seed protein contents of plants occurred, when the plants inoculated with M. incognita or M. javanica and Rhizobium were exposed to either concentration of SO_2 in comparison to unexposed plants with both Rhizobium and nematodes and were also smaller than exposed plants inoculated with Rhizobium. The leaf pigments and seed proteins were highest in simultaneous inoculation exposures and lowest in the post-inoculation exposures (Table 7, Figs. 1C and 1D).

Leaf epidermal characters

Stomata and trichome-hydathodes on the leaf surfaces of chick-pea were adversely affected by SO_2 exposures but the trichomes responded favourably. The effects of 0.2 ppm SO_2 were greater than 0.1 ppm. Number and size of stomata and the number and length of trichome-hydathodes decreased significantly due to SO_2 exposure . The reduction in the size of stomatal aperture was also significant at P = 0.05. Rhizobium inoculation increased the number of stomata, size of stomata and stomatal aperture and the number and length of trichome-hydathodes. When Rhizobium inoculated plants were exposed to 0.1 or 0.2 ppm SO_2, all these parameters of epidermal characters were reduced.These parameters in

exposed plants inoculated with Rhizobium were significantly greater than the exposed plants without Rhizobium. M. incognita and M. javanica adversely affected these epidermal characters. In the root-knot nematode inoculated plants exposed to SO_2, the measures of epidermal characters (stomata and trichome-hydathodes) were significantly smaller than inoculated unexposed plants or the uninoculated plant exposed to SO_2. In the plants inoculated with Rhizobium and M. incognita, the number of stomata on lower surface and trichome-hydathodes on upper surface (at $P = 0.01$) and number of stomata on upper surface (at $P = 0.05$) increased significantly. Increase in the size of stomata, length of trichome-hydathodes on both surfaces and number of trichomes-hydathodes on lower surface and decrease in the size of stomatal aperture on both surfaces were not significant. Rhizobium together with M. javanica increased significantly the number and size of stomata and the number and length of trichome-hydathodes. Increase in the size of stomatal aperture on lower surface and decrease on the upper surface were not significant. In the plants inoculated with M. javanica and Rhizobium when exposed to 0.1 ppm SO_2, the number of stomata on lower surface and the number and length of trichome-hydathodes on both the leaf surfaces were greater than unexposed plants (control), while other parameters were smaller. In the plants inoculated with M. incognita together with Rhizobium and exposed to 0.1 ppm

Table 8. Interactive effects of SO_2, root-knot nematodes and root nodule bacteria on number of stomata on leaves of chick-pea.

Treatment		Number of stomata/cm^2								
		C	0.1 ppm			0.2 ppm			L.S.D.	
			Pe	S	Pt	Pe	S	Pt	0.01	0.05
P (Control)	L	24992.12	23577.47	23560.82	23582.45	22919.62	22928.55	22939.52	564.75	416.75
	U	14884.45	12965.78	12968.43	12614.76	12624.23	12622.76	12625.83	544.33	401.68
P+Rh	L	30240.45	27332.87	27349.83	27350.42	25435.59	25450.69	25450.73	656.28	484.29
	U	17160.17	15310.65	15324.26	14260.84	14260.12	14263.12	14290.54	589.74	534.19
P+Mi	L	23140.26	22242.90	22454.74	22035.02	21836.72	22046.58	21630.70	534.89	394.71
	U	12452.02	12014.93	12127.22	11904.76	11851.86	11964.20	11741.61	426.49	314.72
P+Rh+Mi	L	25916.74	24244.76	24700.21	23797.82	23365.29	23510.42	22928.55	582.55	429.88
	U	14344.72	13336.57	13703.75	12976.12	12681.49	13040.97	12328.69	519.87	383.63
P+Mj	L	23801.36	22497.59	22670.65	22454.74	22089.16	22260.73	23845.69	591.46	436.46
	U	12879.11	12149.93	12241.62	12127.22	11986.92	12078.69	11964.20	529.23	390.54
P+Rh+Mj	L	27847.42	25197.30	25844.50	24700.21	23856.30	24264.19	25037.48	540.79	399.07
	U	15352.25	13850.92	14200.28	13582.48	13065.74	13407.34	12801.69	594.61	438.78
L.S.D.										
0.01	L	678.46	567.13	587.23	654.99	584.41	574.66	567.32		
	U	520.92	498.15	505.80	490.14	502.55	506.79	472.59		
0.05	L	497.46	415.83	430.57	480.25	428.50	421.35	415.97		
	U	381.95	365.25	370.86	359.38	368.48	371.59	346.51		

L = Lower surface, U = Upper surface

Each value is mean of five replicates.

Table 9. Interactive effects of SO_2, root-knot nematodes and root nodule bacteria on **size of stomata and stomatal aperture on leaves of chick-pea.**

Treatment		Size of stomata (μm^2)									Size of stomatal aperture (μm^2)								
			0.1 ppm			0.2 ppm			L.S.D.			0.1 ppm			0.2 ppm			L.S.D.	
		C	Pe	S	Pt	Pe	S	Pt	0.01	0.05	C	Pe	S	Pt	Pe	S	Pt	0.01	0.05
P (Control)	L	396.33	356.45	357.05	356.83	350.45	350.73	352.89	34.80	24.68	86.44	83.76	83.92	83.99	82.26	82.32	82.34	5.04	3.72
	U	378.45	334.96	334.91	335.42	329.59	329.09	329.40	33.36	24.62	62.50	60.11	60.10	60.17	58.89	58.96	59.04	3.33	2.46
P+Rh	L	459.74	395.78	396.33	396.24	381.86	382.30	382.24	44.12	32.56	96.81	96.21	91.48	91.77	88.02	88.09	88.15	5.33	3.93
	U	446.52	378.45	378.45	379.13	364.83	365.29	365.75	44.38	32.75	71.88	66.65	66.71	66.80	63.68	63.65	63.77	3.93	2.90
P+Mi	L	360.61	336.83	341.68	333.70	334.03	337.89	330.88	30.94	22.83	75.17	73.94	74.60	73.62	73.50	74.17	73.18	3.23	2.38
	U	340.94	310.10	314.47	307.26	309.00	311.93	306.13	29.30	21.62	53.65	52.49	52.95	52.26	52.41	52.88	52.18	2.55	1.88
P+Rh+Mi	L	402.27	358.72	369.01	352.05	354.07	361.55	347.43	37.59	27.74	81.18	78.38	79.82	77.66	77.18	78.62	76.47	3.27	2.41
	U	387.26	334.91	344.34	327.23	327.54	333.78	321.43	39.77	29.35	59.55	56.68	57.71	55.92	54.51	55.53	53.74	2.93	2.16
P+Mj	L	376.59	341.68	343.32	340.05	337.24	339.86	337.24	34.72	25.62	78.58	76.64	77.71	76.29	75.87	76.94	75.53	3.18	2.35
	U	352.69	318.36	320.49	315.95	316.43	318.88	313.42	28.32	20.83	55.31	54.14	54.63	53.66	54.34	55.10	53.60	2.37	1.75
P+Rh+Mj	L	429.65	369.08	375.94	363.86	360.85	368.75	357.48	45.87	33.85	86.59	82.01	83.92	80.87	80.43	82.32	79.63	3.67	2.71
	U	410.12	348.60	355.74	342.81	343.33	349.17	334.92	41.71	30.78	61.95	59.28	60.37	58.22	57.60	58.96	56.28	2.82	2.08
L.S.D.																			
0.01	L	29.42	27.89	30.77	26.94	25.08	28.03	29.12			7.80	7.26	7.45	7.16	5.86	5.99	6.25		
	U	31.48	29.62	27.66	30.52	26.43	25.31	27.90			6.59	6.31	6.16	5.99	5.62	5.77	5.50		
0.05	L	21.57	20.45	22.56	19.75	18.39	20.55	21.35			5.72	5.32	5.46	5.25	4.28	4.39	4.58		
	U	23.08	21.72	20.28	22.38	19.38	18.56	20.46			4.83	4.65	4.52	4.39	4.12	4.23	4.03		

L = Lower surface, U = Upper surface

Each value is mean of five replicates.

Table 10. Interactive effects of SO_2, root-knot nematodes and root nodule bacteria on number and length of trichome-hydathodes on leaves of chick-pea.

Treatment		Number of trichome-hydathodes/cm²									Length of trichome-hydathodes (µm)								
			0.1 ppm			0.2 ppm			L.S.D.			0.1 ppm			0.2 ppm			L.S.D.	
		C	Pe	S	Pt	Pe	S	Pt	0.01	0.05	C	Pe	S	Pt	Pe	S	Pt	0.01	0.05
P (Control)	L	651.39	586.29	586.29	587.15	571.18	571.29	571.48	65.36	48.23	424.00	390.95	392.59	392.84	385.28	285.45	385.78	23.53	17.36
	U	411.40	363.87	364.07	364.25	357.62	357.72	357.91	44.38	32.75	404.13	368.58	369.07	369.18	364.02	369.08	364.52	40.06	29.56
P+Rh	L	1097.02	867.97	868.52	868.33	788.45	788.52	789.05	94.14	69.47	562.22	495.55	495.84	495.76	462.37	462.55	462.90	33.28	24.81
	U	828.16	553.21	553.39	553.64	507.64	507.99	508.23	74.90	55.27	545.76	461.10	461.34	461.62	445.11	445.18	445.79	45.34	33.46
P+Mi	L	497.24	473.26	477.10	462.08	472.23	480.16	464.55	32.36	23.88	375.22	363.51	370.37	356.90	360.24	365.36	355.26	19.74	14.57
	U	304.74	282.23	286.67	275.81	288.50	293.23	281.69	27.73	20.46	351.42	335.52	341.73	329.53	335.56	340.26	330.98	25.00	18.45
P+Rh+Mi	L	721.00	642.63	667.95	614.56	604.45	633.82	580.69	46.91	34.62	446.51	418.04	433.35	405.08	414.27	425.64	401.45	26.72	19.72
	U	624.72	395.11	412.80	377.86	378.46	392.93	363.37	50.76	37.46	428.73	392.56	406.67	380.60	385.89	398.11	374.01	32.04	23.64
P+Mj	L	552.03	519.33	528.68	510.29	514.77	524.22	505.66	62.00	45.75	388.90	370.37	373.10	366.91	367.10	370.63	363.64	20.95	15.46
	U	340.04	316.58	320.17	311.17	319.41	325.22	313.81	35.92	26.51	364.08	341.73	344.93	338.60	343.47	346.74	340.26	27.32	20.16
P+Rh+Mj	L	866.69	732.25	766.59	709.31	679.50	712.93	752.30	71.13	52.49	482.24	433.32	448.68	421.95	425.84	437.34	414.56	26.14	19.29
	U	782.14	459.04	477.94	445.56	434.40	452.05	417.36	51.79	38.22	460.56	410.08	424.26	399.54	405.30	416.09	393.70	35.32	27.54
L.S.D. 0.01	L	97.45	89.13	93.12	85.17	81.00	82.21	79.61			40.53	30.78	32.53	34.12	27.14	29.30	27.65		
	U	90.27	83.58	82.36	86.70	71.43	69.31	65.72			45.58	41.26	42.33	35.98	27.89	27.05	30.99		
0.05	L	71.45	65.35	68.28	62.45	59.39	60.28	58.37			29.72	22.57	23.85	25.02	19.90	21.48	20.77		
	U	66.19	61.28	60.39	65.58	52.33	50.28	50.39			34.89	30.25	29.57	26.38	20.45	19.83	22.72		

L = Lower surface, U = Upper surface

Each value is mean of five replicates.

SO_2 and in the plants inoculated with either species of Meloidogyne together with Rhizobium and exposed to 0.2 ppm SO_2 all these parameters were smaller than the unexposed inoculated plants. The measures of leaf epidermal characters were highest and lowest respectively in simultaneous and post-inoculation treatment of SO_2 (0.1 and 0.2 ppm) (Tables 8, 9 and 10).

The number of trichomes on the leaf surfaces of chick-pea and was increased significantly by SO_2 exposures. Rhizobium alone decreased the number and length of trichomes. In the plants inoculated with Rhizobium and exposed to SO_2, the number and length of trichomes were greater than the plants inoculated with Rhizobium alone and were smaller than the uninoculated plants exposed to SO_2. Both M. incognita and M. javanica increased the number and length of trichomes. The number and length of trichomes in plants inoculated with either species of Meloidogyne and exposed to SO_2 were greater than unexposed plants (control) inoculated with the nematode. M. incognita and M. javanica, together with Rhizobium decreased the number and length of trichomes. The number of trichomes in the exposed plants (0.1 and 0.2 ppm) inoculated with both Rhizbium and root-knot nematode was greater than the unexposed plants inocula-

Table 11. Interactive effects of SO_2, root-knot nematodes and root nodule bacteria on **number and length of trichomes on leaves of chick-pea.**

Treatment		Number of trichomes/cm^2									Length of trichomes (μm)								
			0.1 ppm			0.2 ppm			L.S.D.			0.1 ppm			0.2 ppm			L.S.D.	
		C	Pe	S	Pt	Pe	S	Pt	0.01	0.05	C	Pe	S	Pt	Pe	S	Pt	0.01	0.05
P (Control)	L	3039.57	3434.71	3432.68	3435.24	3586.69	3586.84	3586.92	156.21	114.27	331.25	351.13	350.45	351.22	357.75	457.29	357.86	26.89	19.84
	U	1651.24	1898.93	1898.59	1896.45	1981.49	1981.26	1981.78	166.48	122.85	320.75	345.85	345.26	346.04	352.32	352.45	352.96	30.60	22.58
P+Rh	L	1885.89	2320.75	2321.45	2320.67	2508.18	2510.49	2509.04	182.39	134.59	238.65	270.10	270.02	270.43	281.69	281.71	281.84	30.68	22.64
	U	988.62	1241.13	1241.08	1241.76	1347.95	1347.38	1348.21	118.38	87.36	230.11	260.06	259.86	260.28	271.01	271.16	271.62	23.11	17.05
P+Mi	L	3556.30	3881.23	3812.53	3949.52	4017.10	3945.36	4088.83	169.19	124.85	371.00	382.73	379.22	386.24	386.37	382.79	389.95	19.66	14.51
	U	2030.73	2221.74	2183.74	2259.72	2278.71	2239.08	2318.34	178.40	171.35	380.93	383.93	389.47	387.39	380.50	376.98	384.02	19.45	14.35
P+Rh+Mi	L	2694.17	2853.84	2742.83	2949.70	2997.83	2858.96	3097.60	164.36	121.29	304.10	321.62	310.83	330.12	327.43	318.99	336.16	24.16	17.83
	U	1430.09	1486.96	1516.50	1637.38	1675.52	1610.85	1743.11	152.57	112.59	323.82	319.94	309.32	328.29	325.21	314.15	333.93	17.41	12.85
P+Mj	L	3373.92	3692.32	3623.62	3743.84	2819.83	3766.03	3855.69	181.15	133.68	361.06	373.95	370.44	377.46	377.43	373.85	381.00	20.81	15.36
	U	1915.16	2098.71	2060.33	2126.80	2149.91	2110.28	2179.64	166.41	122.80	367.64	373.55	370.09	375.28	376.98	373.46	378.74	18.50	13.65
P+Rh+Mj	L	2249.28	2528.04	2499.05	2674.17	2767.99	2690.02	2877.38	174.04	128.45	284.29	304.02	294.00	311.95	317.16	308.97	325.64	25.90	19.11
	U	1212.13	1447.11	1392.12	1497.74	1546.70	1486.12	1602.67	185.31	136.75	285.02	298.84	289.14	305.11	309.00	298.77	315.62	19.41	14.32
L.S.D.																			
0.01	L	173.80	170.73	165.53	167.91	164.33	161.85	164.88			31.40	29.08	30.58	29.45	27.09	25.34	24.94		
	U	171.41	159.34	154.53	151.01	168.37	161.28	154.84			37.38	36.24	34.61	35.02	30.81	34.61	33.84		
0.05	L	127.43	125.18	121.37	122.82	120.49	118.67	120.89			22.76	21.32	22.42	20.86	19.86	18.50	18.29		
	U	125.68	116.83	113.45	110.72	123.45	118.25	113.53			27.41	26.57	25.38	24.21	22.59	25.38	24.81		

L = Lower surface, U = Upper surface

Each value is mean of five replicates.

ted with Rhizobium and the root-knot nematode. The number and length of trichomes in exposed plants inoculated with Rhizobium and root-knot nematode were greater than the exposed plants inoculated with Rhizobium. However, the plants inoculated with Rhizobium and M. javanica, number and length of trichomes on upper leaf surface were significantly (P = 0.05) greater due to simultaneous exposure of SO_2 (00.1 ppm and 0.2 ppm) the length of trichomes on lower surface was significantly (P = 0.05) greater in the simultaneous exposure to 0.1 ppm SO_2. Number and length of trichomes were highest in post-inoculation exposures and lowest in simultaneous exposures (Table 11).

OZONE (O_3)

Plant growth and yield

Plant growth and yield of chick-pea were also significantly suppressed by O_3. Like SO_2, ozone at 0.2 ppm was more toxic than 0.1 ppm. In the Rhizobium inoculated plants exposed to O_3, plant growth and yield were reduced in comparison to unexposed Rhizobium inoculated plants. The growth

and yield were, however, significantly greater than the exposed plants without Rhizobium. Plant growth and yield parameters in the plants inoculated with either M. incognita and M. javanica and exposed to either concentration of O_3 were reduced in comparison to unexposed nematode inoculated plants. Plant growth parameters were non-significantly smaller than the exposed plants without nematode inoculation. But the yield was significantly reduced. When plants inoculated with both Rhizobium and either species of Meloidogyne were exposed, the plant growth and yield were reduced in comparison to unexposed plants with Rhizobium and and nematode. Plant growth parameters of M.incognita inoculated plants were affected variously, while yield parameters were significantly smaller in comparison to the uninoculated plants treated with O_3. All these parameters in M. incognita inoculated plants were significantly smaller than the exposed plants inoculated with Rhizobium. Plant growth and yield of plants inoculated with M. javanica and Rhizobium were greater than uninoculated plants and were smaller than the Rhizobium inoculated and exposed plants. All the growth and yield parameters were highest in simultaneous inoculation exposures and lowest in post-inoculation expo sures (Tables 12 and 13, Figs. 2A and 2B).

Table 12. Interactive effects of O_3, root-knot nematodes and root nodule bacteria on plant length and fresh weight of chick-pea.

Treatment		Length (cm)								Fresh weight (g)							
		0.01 ppm			0.2 ppm			L.S.D.		0.1 ppm				0.2 ppm			L.S.D.	
	C	Pe	S	Pt	Pe	S	Pt	0.01	0.05	C	Pe	S	Pt	Pe	S	Pt	0.01	0.05
P (Control)	S 32.6	24.9	25.0	25.0	20.2	20.3	20.2	3.20	2.36	25.25	19.05	19.05	19.10	14.70	14.70	14.70	3.33	2.46
	R 22.7	17.5	17.6	17.6	14.7	14.7	14.7	2.24	1.65	17.50	13.45	13.45	13.47	11.05	11.10	11.10	2.55	1.88
P+Rh	S 42.4	29.3	29.3	29.4	22.9	22.9	22.9	5.08	3.75	38.55	23.40	23.45	23.45	17.15	17.15	17.15	4.27	3.15
	R 27.5	20.0	20.2	20.2	16.4	16.4	16.5	2.86	2.11	24.25	16.10	16.15	16.15	12.45	12.50	12.50	3.14	2.32
P+Mi	S 25.2	21.2	21.9	20.8	17.7	18.3	17.4	2.90	2.14	21.85	17.30	17.65	17.15	13.65	13.95	13.55	2.86	2.11
	R 16.4	14.7	15.1	14.4	12.8	13.1	12.5	2.09	1.54	14.80	12.25	12.45	12.00	10.25	10.45	10.05	1.86	1.37
P+Rh+Mi	S 30.7	23.5	25.1	22.9	18.9	19.9	18.4	3.92	2.89	30.40	19.90	21.00	19.40	15.05	15.60	14.90	3.24	2.39
	R 19.6	16.0	16.9	15.4	13.5	14.3	13.2	2.49	1.84	18.30	13.70	14.35	13.35	11.10	11.60	10.80	2.60	1.92
P+Mj	S 29.3	24.0	24.2	23.9	19.7	19.8	19.6	2.62	2.67	24.15	18.60	18.70	18.40	14.45	14.65	14.41	3.50	2.58
	R 19.8	16.6	16.9	16.5	14.1	14.2	13.9	2.24	1.65	16.75	13.05	13.20	13.00	10.80	10.90	10.75	2.22	1.64
P+Rh+Mj	S 36.4	26.9	27.8	26.6	21.5	21.9	21.2	3.43	2.53	34.15	22.15	22.60	21.75	16.25	16.65	16.05	4.42	3.26
	R 23.9	18.3	19.1	17.9	15.1	15.7	14.8	2.57	1.90	21.85	15.15	15.55	14.95	11.90	12.15	11.75	2.53	1.87
L.S.D.																		
0.01	S 3.72	3.07	3.15	2.99	2.29	2.48	2.37			2.03	2.29	2.07	1.94	1.70	1.81	1.61		
	R 1.73	1.69	1.61	1.47	1.34	1.40	1.39			1.55	1.60	1.53	1.55	1.50	1.19	1.39		
0.05	S 2.73	2.25	2.31	2.19	1.68	1.82	1.74			1.49	1.68	1.52	1.42	1.25	1.33	1.18		
	R 1.27	1.24	1.18	1.06	0.98	1.03	1.02			1.14	1.17	1.12	1.14	1.10	0.87	1.02		

C = Control, Pe = Pre-inoculation, S = Simultaneous inoculation, Pt = Post-inoculation, P = Plant, Rh = Rhizobium, Mi = Meloidogyne incognita, Mj = M. javanica, (These abbreviations and common to all subsequent tables).

S = Shoot, R = Root

Each value is mean of five replicates.

Table 13. Interactive effects of O_3, root-knot nematodes and root nodule bacteria on dry weight, flowering and fruiting of chick-pea.

Treatment		Dry weight (g)								Flower/Fruit								
			0.1 ppm			0.2 ppm			L.S.D.			0.1 ppm			0.2 ppm			L.S.D.	
		C	Pe	S	Pt	Pe	S	Pt	0.01	0.05	C	Pe	S	Pt	Pe	S	Pt	0.01	0.05
P (Control)	S	5.80	4.60	4.60	4.60	3.75	3.75	3.80	0.61	0.45	FL 96.8	57.4	57.4	57.6	45.6	45.6	45.6	6.69	4.94
	R	4.15	3.30	3.30	3.30	2.80	2.85	2.85	0.53	0.39	FR 64.6	33.6	35.6	35.4	27.8	27.8	27.8	5.12	3.78
P+Rh	S	8.95	5.80	5.85	5.85	4.45	4.50	4.50	1.10	0.81	FL 150.4	66.2	66.2	66.4	49.4	49.4	49.6	10.60	7.82
	R	5.75	4.10	4.15	4.15	3.35	3.35	3.35	0.65	0.48	FR 110.2	45.2	45.2	45.4	34.4	34.6	34.6	5.75	4.23
P+Mi	S	5.10	4.25	4.30	3.20	3.45	3.55	3.45	0.88	0.65	FL 58.8	39.2	40.4	38.2	32.4	33.6	31.8	5.11	3.77
	R	3.45	3.00	3.10	2.95	2.65	2.70	2.60	0.37	0.27	FR 35.8	21.4	22.4	21.6	18.8	19.8	18.6	3.35	2.47
P+Rh+Mi	S	7.20	4.90	5.15	4.80	3.85	4.00	3.90	0.99	0.73	FL 70.2	43.0	45.4	41.8	33.8	35.6	33.0	5.76	4.25
	R	4.00	3.45	3.60	3.35	2.90	3.00	2.80	0.51	0.38	FR 45.4	26.6	28.4	25.8	22.2	23.8	21.4	3.82	2.82
P+Mj	S	5.45	4.55	4.55	4.50	3.70	3.55	3.65	0.80	0.59	FL 70.4	47.2	48.6	46.4	39.4	39.8	38.8	5.68	4.19
	R	3.85	3.25	3.25	3.20	2.75	2.80	2.75	0.41	0.30	FR 48.0	28.2	28.8	28.8	23.8	24.2	23.4	4.59	3.39
P+Rh+Mj	S	8.15	5.50	5.60	5.40	4.20	4.10	4.15	1.07	0.79	FL 98.2	52.2	55.2	51.0	41.4	42.4	40.2	6.48	4.78
	R	4.90	3.85	3.95	3.80	3.15	3.20	3.10	0.47	0.35	FR 67.2	35.8	37.4	35.2	28.4	29.6	27.6	5.31	3.92
L.S.D.																			
0.01	S	0.94	0.57	0.53	0.55	0.44	0.49	0.38			FL 6.30	4.65	4.61	4.57	4.30	4.43	4.20		
	R	0.65	0.48	0.40	0.49	0.35	0.30	0.26			FR 5.40	4.46	4.51	4.28	3.90	3.74	3.82		
0.05	S	0.69	0.42	0.39	0.40	0.32	0.36	0.28			FL 4.62	3.41	3.38	3.35	3.15	3.25	3.08		
	R	0.46	0.35	0.29	0.36	0.24	0.22	0.19			FR 3.96	3.27	3.31	3.14	2.86	2.74	2.80		

S = Shoot, R = Root

FL = Flower, FR = Fruit

Each value is mean of five replicates.

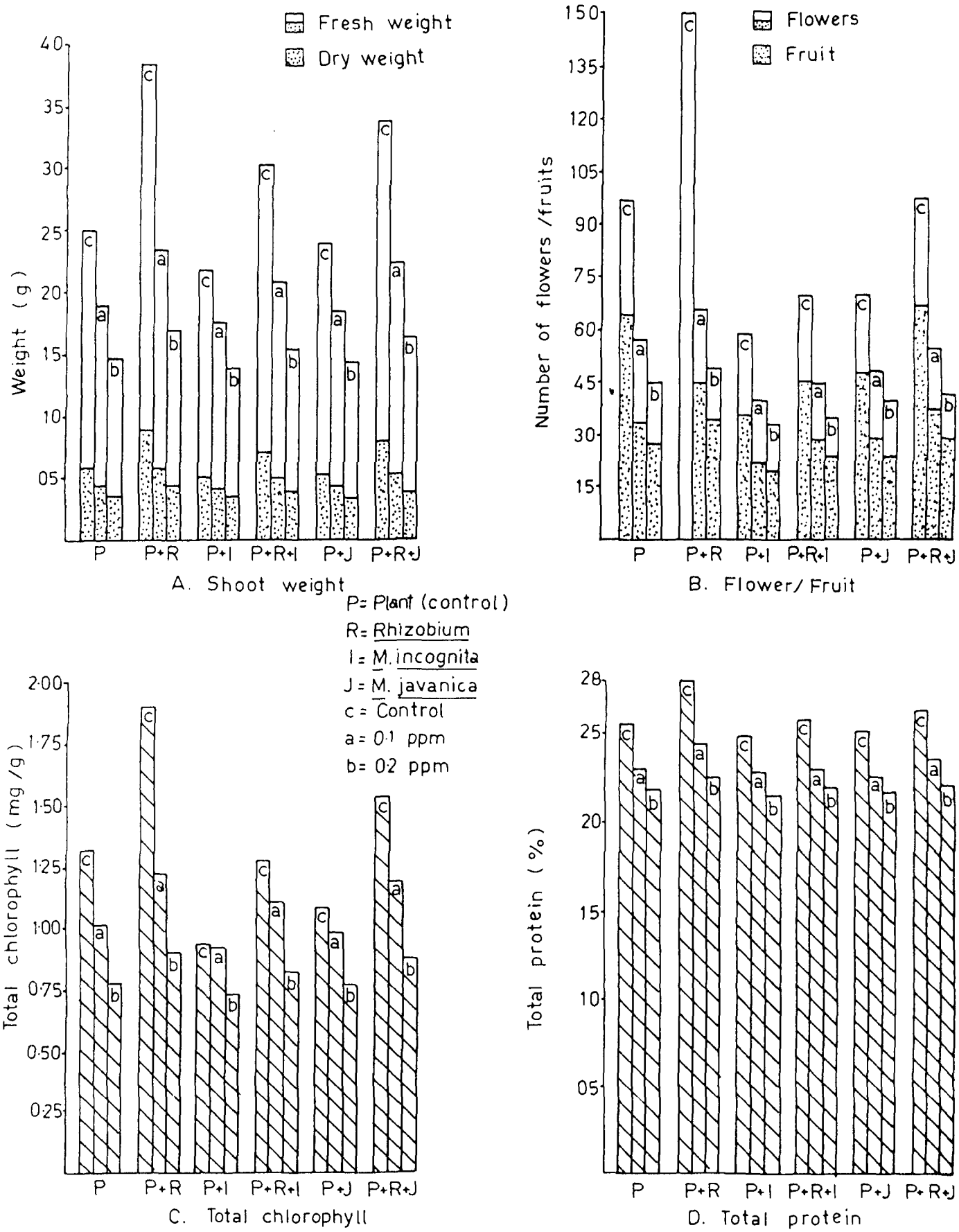

Fig. 2. Interactive effects of O_3, root-knot nematodes and root nodule bacteria on some parameters of chick-pea in simultaneous inoculation exposure.

Root-knot disease and root nodulation

O_3 significantly suppressed root-knot disease and root nodulation at both the concentrations; being greater at 0.2 ppm. The number of galls and eggmasses in Rhizobium inoculated exposed plants were smaller than unexposed plants inoculated with Rhizobium and either species of Meloidogyne or than root-knot nematode inoculated exposed plants. The number of galls and eggmasses was greatest in post-inoculation exposure and lowest in simultaneous inoculation exposure (Table 14).

The number of total and functional nodules was reduced when the Rhizobium inoculated plants were exposed to O_3 concentrations. When the plants inoculated with Rhizobium and either species of Meloidogyne were exposed to O_3, the number of nodules were reduced and the number was smaller than unexposed plants or the Rhizobium inoculated exposed plants. The number of total and functional nodules was highest in simultaneous inoculation exposure and lowest in post-inoculation exposure of plants to O_3. The number of nodules infected with root-knot nematodes was reduced in the O_3 exposed plants. Number of infected nodules were highest in pre-inoculation exposures and lowest in simultaneous exposures (Table 14).

Leaf pigments and seed proteins

Leaf pigments and seed proteins were significantly reduced by the O_3 exposures. The reductions were greater

Table 14. Interactive effects of O_3, root-knot nematodes and root nodule bacteria on root galling, eggmass production and root nodulation on chick-pea.

Treatment		Galls/Eggmass								Nodule								
		0.1 ppm			0.2 ppm			L.S.D.		0.01 ppm				0.2 ppm			L.S.D.	
		C	Pe	S	Pt	Pe	S	Pt	0.01	0.05	C	Pe	S	Pt	Pe	S	Pt	0.01	0.05
P																			
P+Rh																			
											T 140.4	73.4	73.6	74.0	65.6	65.8	65.8	8.39	6.19
											F 120.6	55.6	55.6	55.6	47.4	47.4	47.6	7.11	5.25
											I –	–	–	–	–	–	–	–	–
P+Mi	G	176.2	113.4	92.2	118.6	88.6	72.4	92.4	10.23	7.55									
	E	108.6	40.2	32.6	41.8	29.0	23.4	30.6	7.56	5.58									
P+Rh+Mi	G	125.6	82.0	66.8	86.4	64.2	51.0	67.2	7.75	5.72	T 100.2	51.6	56.4	47.6	46.0	49.2	44.2	7.22	5.33
	E	86.–	29.2	23.4	30.2	21.4	16.2	22.4	5.81	4.29	F 70.8	36.2	41.4	33.2	29.2	34.8	30.4	6.48	4.78
											I 15.2	8.6	7.0	7.4	7.2	5.6	5.8	1.60	1.18
P+Mj	G	83.4	61.2	49.6	63.4	49.6	39.2	51.8	6.55	4.83									
	E	48.6	23.4	19.6	24.8	18.2	14.2	18.6	5.34	3.94									
P+Rh+Mj	G	52.2	38.8	31.2	40.4	30.2	25.8	32.4	4.95	3.65	T 125.4	60.2	67.0	51.4	53.2	57.4	52.4	7.98	5.89
	E	33.8	15.2	12.2	16.4	11.2	10.4	12.4	4.42	3.26	F 100.6	44.2	50.4	42.2	38.6	42.2	37.6	6.90	5.09
											I 11.2	7.8	6.2	6.6	6.2	4.8	5.4	1.49	1.10
L.S.D.																			
0.01	G	8.05	7.36	6.95	7.23	5.96	6.03	8.93			T 18.46	7.68	7.38	6.93	6.24	6.49	5.94		
	E	7.40	5.08	4.42	4.49	3.13	2.92	2.96			F 13.30	6.10	5.66	5.70	5.31	5.40	4.76		
											I 3.17	1.08	0.85	0.90	0.80	0.60	0.65		
0.05	G	5.74	5.25	4.96	5.16	4.25	4.30	4.23			T 12.69	5.28	5.07	4.76	4.29	4.46	4.08		
	E	5.28	3.62	3.15	3.20	2.23	2.08	2.11			F 9.14	4.19	3.89	3.92	3.65	3.71	3.27		
											I 1.91	0.65	0.51	0.54	0.48	0.36	0.39		

G = Gall, E = Eggmass

T = Total, F = Functional, I = Infected

Each value is mean of five replicates.

due to 0.2 ppm O_3 than 0.1 ppm. When the Rhizobium inoculated plants were exposed to either concentration of O_3, the leaf pigments and seed proteins were reduced in comparison to unexposed plants. But the leaf pigments and seed proteins in 0.1 ppm exposure were significantly greater than uninoculated exposed plants. Soluble protein in 0.2 ppm O_3 exposure of plants was greater than unexposed plants in pre- and simultaneous inoculation exposure (significant at $P = 0.05$) and post-inoculation exposure (significant at $P = 0.01$). Insoluble and total proteins were greater than exposed plants without Rhizobium. Leaf pigments and seed proteins in the exposed plants inoculated with either M. incognita or M. javanica were smaller than unexposed plants inoculated with root-knot nematodes or than the exposed uninoculated plants. Leaf pigments and seed proteins in the plants inoculated with Rhizobium and M. incognita or M. javanica and exposed to 0.1 and 0.2 ppm O_3 were reduced and the values were smaller than unexposed plants inoculated with Rhizobium and root-knot nematodes and to the exposed plants inoculated with Rhizobium. Leaf pigments in the exposed plants inoculated with Rhizobium and root-knot nematodes were smaller than the exposed plants without any inoculation. Seed protein contents in exposed plants inoculated with Rhizobium and root-knot nematode were affected variously when compared

Table 15. Interactive effects of O_3, root-knot nematodes and root nodule bacteria on chlorophyll content of leaves and protein content of seeds of chick-pea.

Treatment		Chlorophyll (mg/g)									Protein (%)								
			0.1 ppm			0.2 ppm			L.S.D.			0.1 ppm			0.2 ppm			L.S.D.	
		C	Pe	S	Pt	Pe	S	Pt	0.01	0.05	C	Pe	S	Pt	Pe	S	Pt	0.01	0.05
P (Control)	A	0.621	0.479	0.479	0.481	0.374	0.374	0.374	0.072	0.052	S 11.30	9.62	9.64	9.64	8.62	8.64	8.64	0.56	0.41
	B	0.571	0.431	0.431	0.434	0.336	0.334	0.337	0.062	0.046	I 14.36	13.46	13.46	13.46	13.14	13.16	13.20	0.64	0.47
	T	1.313	1.011	1.011	1.015	0.789	0.788	0.792	0.133	0.098	T 25.66	23.08	23.10	23.10	21.76	21.80	21.84	1.25	0.92
P+Rh	A	0.943	0.584	0.587	0.587	0.431	0.431	0.434	0.099	0.073	S 12.34	10.22	10.22	10.22	8.96	8.96	8.98	0.53	0.39
	B	0.878	0.528	0.530	0.530	0.387	0.387	0.389	0.087	0.064	I 15.62	14.22	14.26	14.26	13.68	13.70	13.70	0.69	0.51
	T	1.901	1.237	1.239	1.239	0.911	0.911	0.913	0.186	0.137	T 27.96	24.44	24.48	24.48	22.64	22.66	22.68	1.60	1.18
P+Mi	A	0.447	0.436	0.445	0.433	0.346	0.352	0.343	0.043	0.032	S 10.94	9.42	9.52	9.40	8.54	8.58	8.48	0.61	0.45
	B	0.412	0.392	0.399	0.388	0.309	0.314	0.306	0.039	0.029	I 13.96	13.22	13.28	13.18	12.94	13.00	12.88	0.84	0.62
	T	0.945	0.921	0.938	0.913	0.731	0.745	0.725	0.098	0.072	T 24.90	22.64	22.80	22.58	21.48	21.58	21.36	1.63	1.20
P+Rh+Mi	A	0.612	0.500	0.527	0.487	0.380	0.394	0.376	0.073	0.054	S 11.40	9.60	9.64	9.54	8.66	8.74	8.64	0.47	0.35
	B	0.559	0.451	0.475	0.439	0.340	0.353	0.337	0.064	0.047	I 14.38	13.38	13.48	13.36	13.20	13.24	13.14	0.57	0.42
	T	1.285	1.056	1.112	1.021	0.802	0.831	0.795	0.160	0.118	T 25.78	22.98	23.12	22.90	21.60	21.98	21.78	1.03	0.76
P+Mj	A	0.520	0.468	0.470	0.465	0.366	0.369	0.366	0.062	0.046	S 11.10	9.48	9.54	9.44	8.60	8.62	8.56	0.57	0.42
	B	0.479	0.420	0.395	0.416	0.327	0.331	0.326	0.047	0.035	I 14.06	13.28	13.34	13.26	13.02	13.12	13.00	0.51	0.38
	T	1.094	0.987	0.992	0.977	0.772	0.780	0.769	0.130	0.096	T 25.16	22.76	22.88	22.70	21.60	21.74	21.56	1.15	0.85
P+Rh+Mj	A	0.729	0.554	0.576	0.545	0.410	0.420	0.405	0.084	0.062	S 11.68	9.76	9.84	9.72	8.74	8.82	8.70	0.76	0.56
	B	0.660	0.500	0.435	0.491	0.368	0.377	0.363	0.079	0.058	I 14.72	13.68	13.74	13.64	13.32	13.36	13.22	0.84	0.62
	T	1.539	1.171	1.196	1.150	0.866	0.887	0.855	0.188	0.139	T 26.40	23.44	23.58	23.36	23.06	22.18	21.92	1.65	1.22
L.S.D.																			
0.01	A	0.060	0.048	0.042	0.044	0.040	0.038	0.034			S 0.65	0.48	0.44	0.41	0.34	0.35	0.35		
	B	0.057	0.040	0.035	0.037	0.031	0.034	0.033			I 0.63	0.49	0.48	0.49	0.37	0.35	0.40		
	T	0.106	0.094	0.085	0.097	0.072	0.065	0.059			T 0.97	0.81	0.85	0.86	0.56	0.61	0.59		
0.05	A	0.044	0.035	0.031	0.032	0.029	0.028	0.025			S 0.48	0.35	0.32	0.30	0.25	0.26	0.25		
	B	0.042	0.029	0.026	0.027	0.023	0.025	0.024			I 0.46	0.36	0.35	0.36	0.27	0.26	0.29		
	T	0.078	0.069	0.072	0.071	0.053	0.048	0.043			T 0.71	0.61	0.62	0.63	0.41	0.45	0.43		

A = Chl.a, B = Chl. b, T = Total

S = Soluble, I = Insoluble, T = Total

Each value is mean of five replicates.

Table 16. Interactive effects of O_3, root-knot nematodes and root nodule bacteria on number of stomata on leaves of chick-pea.

Treatment		Number of stomata/ cm^2							
			0.1 ppm			0.2 ppm			L.S.D.
		C	Pe	S	Pt	Pe	S	Pt	0.01	0.05
P (Control)	L	24992.12	22719.84	22720.11	22722.45	22116.05	22116.92	22116.76	655.37	483.62
	U	13884.45	12396.78	12396.83	12397.62	12073.29	12073.45	12074.78	469.65	346.57
P+Rh	L	30240.45	24764.26	24764.92	24765.78	23664.78	23665.11	23665.59	767.40	566.29
	U	17160.17	13760.42	13768.48	13761.27	13037.56	13039.31	13039.56	787.66	581.24
P+Mi	L	23140.26	21535.65	21741.73	21434.07	21266.27	21472.74	21164.52	796.49	587.76
	U	12452.02	11640.22	11750.55	11585.82	11498.51	11609.07	11444.01	504.10	371.99
P+Rh+Mi	L	25916.74	22827.79	23263.65	22505.77	22074.39	22546.78	21799.45	587.56	433.58
	U	14344.72	12571.43	12808.10	12396.83	12073.41	12305.62	11901.78	496.55	366.42
P+Mj	L	23801.36	21846.26	22058.36	21846.26	22116.92	21683.26	21472.74	653.41	482.17
	U	12879.11	11806.51	11920.30	11806.51	11642.66	11721.78	11609.07	549.85	405.75
P+Rh+Mj	L	27847.42	23560.12	23823.03	23157.03	23222.77	22984.25	22331.65	715.25	527.81
	U	15352.25	12809.09	13112.03	12751.03	12341.22	12542.31	12189.53	648.12	478.27
L.S.D.										
0.01	L	678.46	525.70	560.93	573.66	502.68	482.01	491.74		
	U	520.92	472.00	463.60	480.99	401.97	424.73	439.82		
0.05	L	492.46	385.45	411.28	420.62	368.57	353.42	360.55		
	U	381.95	346.08	339.92	352.67	294.73	311.42	322.48		

L = Lower surface, U = Upper surface

Each value is mean of five replicates.

Table 17. Interactive effects of O_3, root-knot nematodes and root nodule bacteria on size of stomata and stomatal aperture on leaves of chick-pea.

Treatment		Size of stomata (μm^2)								Size of stomatal aperture (μm^2)							
			0.1 ppm			0.2 ppm			L.S.D.			0.1 ppm			0.2 ppm			L.S.D.	
		C	Pe	S	Pt	Pe	S	Pt	0.01	0.05	C	Pe	S	Pt	Pe	S	Pt	0.01	0.05
P (Control)	L	396.3	353.62	353.87	353.83	344.52	344.63	344.92	34.38	25.37	86.44	83.24	83.12	83.27	81.41	81.55	81.45	5.76	4.25
	U	378.45	331.58	331.97	332.10	323.46	323.18	323.59	30.68	22.64	62.50	58.58	58.96	58.92	57.62	57.87	57.92	4.53	3.34
P+Rh	L	459.74	385.69	385.71	386.11	368.24	368.76	368.59	43.16	31.85	96.41	88.90	88.93	89.11	85.60	85.62	85.76	5.39	3.98
	U	446.57	366.29	338.49	368.86	349.34	349.27	349.68	44.16	31.59	71.88	63.34	65.68	65.78	63.44	61.34	61.60	5.22	3.85
P+Mi	L	360.61	337.02	341.90	333.84	331.38	334.60	328.22	28.02	20.68	75.17	75.91	77.32	74.88	76.21	77.30	74.82	5.08	3.75
	U	340.94	313.18	317,68	310.26	308.06	311.02	305.15	31.74	23.42	53.65	53.35	54.34	52.64	53.58	54.34	52.61	2.66	1.96
P+Rh+Mi	L	402.27	358.92	365.83	352.20	341.32	347.98	334.79	36.79	27.15	81.19	79.70	81.96	78.25	78.12	79.62	76.31	4.35	3.21
	U	387.25	338.24	346.27	331.97	323.46	329.68	317.36	36.03	26.59	59.55	56.03	57.60	54.91	55.30	56.51	53.92	4.46	3.29
P+Mj	L	338.89	341.10	343.56	340.26	336.23	337.88	334.60	38.35	28.30	78.58	78.04	78.79	76.96	76.93	77.65	76.21	4.70	3.47
	U	352.69	317.66	319.21	316.17	312.52	314.04	311.02	26.80	19.78	55.31	54.85	55.36	54.09	54.08	54.59	53.58	2.90	2.14
P+Rh+Mj	L	429.65	370.96	374.48	367.48	353.04	356.46	347.78	35.46	26.17	86.59	83.51	84.30	81.57	79.24	80.77	78.12	4.85	3.58
	U	410.12	346.27	351.13	341.46	331.27	336.02	326.57	33.66	24.84	61.95	58.41	58.28	57.07	56.25	57.32	55.19	3.92	2.89
L.S.D.																			
0.01	L	29.42	24.28	26.25	25.22	25.68	22.19				7.80	5.07	4.94	4.90	4.28	3.98	4.19		
	U	31.88	25.22	22.19	23.61	21.03	22.25				6.59	4.90	4.34	4.46	4.24	4.21	4.12		
0.05	L	21.57	17.80	19.25	18.49	18.83	16.27	17.48			5.72	3.72	3.62	3.59	3.14	2.92	3.07		
	U	23.08	18.49	16.27	17.31	15.42	17.05	14.74			4.83	3.59	3.18	3.27	3.11	3.09	3.02		

L = Lower surface, U = Upper surface

Each value is mean of five replicates.

Table 18. Interactive effects of O_3, root-knot nematodes and root nodule bacteria on number and length of trichome-hydathodes on leaves of chick-pea.

Treatment		Number of trichome-hydathodes/cm^2								Length of trichome-hydathodes (µm)							
			0.1 ppm			0.2 ppm			L.S.D.			0.1 ppm			0.2 ppm			L.S.D.	
		C	Pe	S	Pt	Pe	S	Pt	0.01	0.05	C	Pe	S	Pt	Pe	S	Pt	0.01	0.05
P (Control)	L	651.39	565.84	566.43	566.29	552.03	551.89	552.45	51.28	37.84	424.00	381.62	381.98	382.45	375.22	375.22	375.62	34.24	25.27
	U	411.40	451.39	351.62	351.88	342.64	342.83	342.98	52.20	38.52	404.13	357.64	357.61	358.20	358.18	351.42	351.62	47.20	34.83
P+Rh	L	1097.02	792.68	793.00	793.23	717.62	717.65	717.78	59.96	44.25	562.22	454.56	454.47	454.68	427.51	427.75	427.91	39.37	29.05
	U	828.16	506.24	506.34	506.71	459.23	459.40	460.09	59.21	43.19	545.76	454.02	454.11	454.69	407.28	407.64	407.87	40.21	29.67
P+Mi	L	497.24	492.54	505.74	472.02	492.88	501.85	480.02	34.84	25.71	375.22	362.67	365.53	356.99	357.35	360.79	353.98	25.72	18.98
	U	304.74	303.12	311.17	291.00	303.39	308.86	295.55	26.67	19.68	351.42	344.92	347.21	341.43	331.53	337.90	331.53	23.40	17.27
P+Rh+Mi	L	721.00	645.23	677.69	608.92	601.31	627.31	571.22	80.08	29.58	446.51	412.76	424.02	399.83	382.37	396.87	371.68	34.79	25.67
	U	624.72	409.21	429.41	384.19	379.24	395.34	360.57	42.98	31.72	428.73	375.36	383.28	373.17	361.36	378.45	354.73	39.01	28.79
P+Mj	L	552.03	514.93	524.47	505.74	511.13	520.78	501.84	45.72	33.74	388.90	367.29	370.86	363.79	364.29	367.96	360.79	22.48	18.59
	U	340.04	316.78	322.59	311.17	314.53	320.40	308.86	38.31	28.27	364.08	357.35	360.79	353.98	341.18	344.53	337.76	20.80	15.35
P+Rh+Mj	L	866.69	695.16	718.52	667.57	638.92	661.38	614.76	70.98	52.38	482.24	424.22	435.76	414.72	40.72	412.01	389.65	36.03	26.59
	U	782.14	437.15	451.63	423.19	402.59	416.53	389.16	45.64	33.68	460.56	418.10	429.39	407.08	380.42	391.04	370.04	30.76	22.68
L.S.D.																			
0.01	L	97.45	72.08	75.37	62.44	55.67	49.43	53.42			40.53	27.65	23.99	22.95	21.59	22.16	19.63		
	U	90.27	58.41	56.45	53.95	49.29	44.78	44.68			47.58	44.71	38.19	34.74	38.58	36.07	37.23		
0.05	L	71.45	52.80	55.16	45.78	40.82	36.24	39.17			29.72	20.27	17.59	16.83	15.83	16.25	14.39		
	U	66.19	42.83	41.39	39.56	34.14	32.83	32.76			34.89	31.83	28.53	25.47	28.29	26.45	27.30		

L = Lower surface, U = Upper surface

Each value is mean of five replicates.

est in simultaneous inoculation exposure and lowest in post-inoculation exposure of plants (Tables 16, 17 and 18).

The number and length of trichomes increased significantly at P = 0.01 in the plants exposed to O_3. The increase was greater due to 0.2 ppm O_3 than 0.1 ppm. The increase in length of trichomes on the lower leaf surface due to 0.1 ppm exposure was significant only at P = 0.05. Number and length of trichomes in the exposed plants inoculated with Rhizobium were greater than the unexposed plants and were smaller than the exposed plants without Rhizobium inoculation. In the exposed plants inoculated with either species of Meloidogyne, the number of trichomes were more than the unexposed plants or the exposed plants without root-knot nematode inoculation. Length of trichomes increased non-significantly in pre- and post-inoculation exposures and on the lower leaf surface in the simultaneous exposure of O_3 and decreased on the upper leaf surface in the M. incognita inoculated plants. Length of trichomes in M. javanica inoculated exposed plants increased and the values were greater than unexposed plants. Length of trichomes was greater than the exposed plants without nematode inoculation. The number and length of trichomes in exposed plants inoculated with root-knot nematode alongwith Rhizobium were greater than unexposed plants; Rhizobium inoculated

Table 19. Interactive effects of O_3, root-knot nematodes and root nodule bacteria on number and length of trichomes on leaves of chick-pea.

Treatment		Number of trichomes/cm²									Length of trichomes (μm)								
		C	0.1 ppm			0.2 ppm			L.S.D.		C	0.1 ppm			0.2 ppm			L.S.D.	
			Pe	S	Pt	Pe	S	Pt	0.01	0.05		Pe	S	Pt	Pe	S	Pt	0.01	0.05
F (Control)	L	3039.57	3491.51	3490.25	3493.87	3647.48	3648.25	3645.42	182.06	134.35	331.25	361.06	360.42	360.15	367.69	366.34	366.40	34.27	25.29
	U	1651.24	1940.21	1938.45	1939.78	2022.77	2022.60	2021.24	171.66	126.67	320.75	356.03	356.15	354.92	362.45	362.60	361.14	35.38	24.05
P+Rh	L	1885.58	2532.98	2531.76	2532.14	2805.76	2803.66	2803.98	162.18	119.68	238.65	298.40	298.28	298.34	311.60	311.02	310.72	47.04	34.71
	U	986.62	1376.03	1374.27	1374.64	1520.88	1521.12	1518.91	119.35	88.07	230.11	289.46	288.78	288.02	301.04	301.45	301.61	40.53	29.91
P+Mi	L	3550.30	3862.54	3792.63	3914.97	3921.04	3866.52	3975.75	182.60	134.75	371.00	384.53	379.11	389.94	386.07	384.24	389.75	27.47	20.27
	U	2030.73	2165.33	2124.53	2192.44	2194.71	2164.36	2225.05	155.60	114.82	380.93	382.73	377.39	384.51	384.20	378.76	387.82	19.47	14.37
P+Rh+Mi	L	2694.17	2994.22	2873.20	3107.12	3213.97	3093.06	3340.97	173.35	127.92	304.10	343.32	329.66	354.50	346.26	337.05	354.32	39.95	29.48
	U	1430.09	1625.57	1573.62	1684.49	1755.76	1690.91	1823.81	163.40	130.58	322.82	329.94	319.82	337.23	335.98	329.36	349.39	15.08	11.08
P+Mj	L	3373.92	3705.24	3652.81	3740.20	3793.38	3756.90	3829.85	175.69	129.65	361.06	379.11	375.50	382.72	378.72	375.04	382.39	30.67	22.63
	U	1925.16	2076.02	2046.92	2095.43	2123.91	2103.68	2144.14	146.06	107.78	367.68	377.39	373.83	380.95	376.95	373.32	380.57	26.90	19.85
P+Rh+Mj	L	2249.28	2829.43	2725.98	2922.03	3034.70	2958.19	3063.88	187.89	138.65	284.29	326.82	318.22	335.72	332.21	323.31	341.43	33.99	25.09
	U	1212.43	1549.27	1494.10	1599.56	1672.37	1618.22	1729.14	128.76	95.02	285.02	319.82	311.53	328.41	327.78	319.08	336.77	30.57	22.56
L.S.D.																			
0.01	L	173.80	178.34	170.25	173.91	158.60	164.14	175.24			31.06	24.75	25.97	25.05	22.16	23.35	22.33		
	U	141.41	161.74	164.70	164.32	161.71	158.64	160.13			37.38	33.48	31.74	33.41	31.14	27.71	29.40		
0.05	L	127.43	130.76	124.83	127.51	116.29	120.35	128.49			22.76	18.15	19.04	18.37	16.25	17.12	16.37		
	U	125.68	118.29	120.76	120.48	118.57	116.32	117.41			27.41	24.55	23.27	24.50	22.83	20.32	21.56		

L = Lower surface, U = Upper surface

Each value is mean of five replicates

exposed plants, and exposed plants without any inoculation. The number and length of trichomes were highest in post-inoculation exposure and lowest in the simultaneous inoculation exposure(Table 19).

SULPHUR DIOXIDE AND OZONE MIXTURE (SO_2+O_3)

Plant growth and yield

Plant growth and yield characters were reduced significantly by the mixture of SO_2 and O_3. The effect of 0.2 ppm mixture was greater than 0.1 ppm mixture of the pollutants. When Rhizobium inoculated plants were exposed to SO_2-O_3 mixture, plant growth and yield were reduced in comparison to Rhizobium inoculated unexposed plants. But the plant growth and yield were greater than the exposed plants without Rhizobium inoculation. M. incognita and M. javanica suppressed the plant growth and yield. When the nematode inoculated plants were exposed to SO_2 + O_3, the plant growth and yield were further reduced and the values were smaller than the nematode inoculated unexposed plants or the exposed plants without nematode inoculation. Plant growth and yield parameters were affected variously by M. incognita or M. javanica in plants inoculated with Rhizobium. Plant growth and yield parameters in the SO_2+O_3 exposed plants inoculated with both Rhizobium and root knot

Table 20. Interactive effects of mixtures of SO_2 and O_3, root-knot nematodes and root nodule bacteria on plant length and fresh weight of chick-pea.

Treatment		Length (cm)								Fresh weight (g)								
			0.1+0.1 ppm			0.2+0.2 ppm			L.S.D.			0.1+0.1 ppm			0.2+0.2 ppm			L.S.D.	
		C	Pe	S	Pt	Pe	S	Pt	0.01	0.05	C	Pe	S	Pt	Pe	S	Pt	0.01	0.05
P (Control)	S	32.6	22.4	22.4	22.6	18.1	18.1	18.1	2.63	1.94	25.25	16.60	16.60	16.60	13.20	13.20	13.25	2.33	1.72
	R	22.7	16.2	16.3	16.3	13.2	13.3	13.3	2.28	1.68	17.50	13.35	13.35	13.35	10.35	10.35	10.35	1.94	1.43
P+Rh	S	42.4	25.2	25.3	25.3	19.6	19.7	19.7	3.05	2.25	38.55	19.70	19.75	19.75	14.95	14.95	14.95	2.90	2.14
	R	27.5	17.9	17.8	17.9	14.0	14.0	14.2	2.62	1.93	24.25	15.45	15.50	15.50	11.30	11.30	11.25	2.39	1.76
P+Mi	S	25.2	18.5	20.2	19.2	16.1	16.7	15.8	2.37	1.75	21.85	15.30	15.65	15.10	12.40	12.70	12.20	1.92	1.42
	R	16.4	14.2	14.6	13.9	12.1	12.4	12.0	1.68	1.24	14.80	12.35	12.60	12.35	9.80	9.90	9.70	1.86	1.37
P+Rh+Mi	S	30.7	21.1	22.2	20.7	17.1	17.9	16.7	2.68	1.98	30.40	17.45	18.00	16.90	13.55	14.10	13.10	2.43	1.79
	R	19.6	14.7	15.4	14.5	12.5	12.8	12.3	1.84	1.36	18.30	13.85	14.20	13.75	10.35	10.60	10.20	2.06	1.52
P+Mj	S	29.3	21.9	22.0	21.7	17.8	18.0	17.7	2.76	2.04	24.15	16.20	16.35	16.25	13.40	13.10	12.90	2.07	1.53
	R	19.8	15.8	15.9	15.7	13.1	13.2	13.1	1.92	1.42	16.75	13.05	13.15	13.00	10.14	10.20	10.10	2.17	1.60
P+Rh+Mj	S	36.4	24.1	24.4	23.8	19.3	19.6	19.1	3.20	2.36	34.15	18.55	19.05	18.25	14.25	14.55	14.30	2.76	2.04
	R	23.9	17.1	17.5	16.9	13.9	14.1	13.7	2.34	1.73	21.85	14.60	15.00	14.50	10.85	10.80	10.70	2.36	1.74
L.S.D.																			
0.01	S	3.72	2.48	2.56	2.37	1.72	1.90	1.73			2.03	1.57	1.61	1.49	1.19	1.25	1.12		
	R	1.73	1.43	1.49	1.30	1.19	1.00	1.12			1.55	1.06	1.10	1.16	0.95	0.85	0.90		
0.05	S	2.73	1.82	1.88	1.74	1.26	1.39	1.27			1.49	1.15	1.18	1.09	0.87	0.92	0.82		
	R	1.27	1.05	1.09	0.95	0.87	0.73	0.82			1.14	0.78	0.81	0.85	0.70	0.62	0.66		

C = Control, Pe = Pre-inoculation, S = Simultaneous inoculation Pt = Post-inoculation, P = Plant, Rh = *Rhizobium*, Mi = *Meloidogyne incognita*, Mj = ***M.javanica*** , (These abbreviations are common to all subsequent tables).

S = Shoot, R = Root.

Table 21. Interactive effects of mixtures of SO_2 and O_3, root-knot nematodes and root nodule bacteria on dry weight, flowering and fruiting of chick-pea.

Treatment		Dry weight (g) C	0.1+0.1 ppm Pe	0.1+0.1 ppm S	0.1+0.1 ppm Pt	0.2+0.2 ppm Pe	0.2+0.2 ppm S	0.2+0.2 ppm Pt	L.S.D. 0.01	L.S.D. 0.05		Flower/Fruit C	0.1+0.1 ppm Pe	0.1+0.1 ppm S	0.1+0.1 ppm Pt	0.2+0.2 ppm Pe	0.2+0.2 ppm S	0.2+0.2 ppm Pt	L.S.D. 0.01	L.S.D. 0.05
P (Control)	S	5.80	4.10	4.15	4.15	3.10	3.40	3.45	0.62	0.48	FL	96.8	51.6	51.8	51.8	42.2	42.6	42.6	6.99	5.16
	R	4.15	3.35	3.35	3.35	2.65	2.65	2.70	0.53	0.39	FR	64.6	31.2	31.2	31.6	25.2	25.2	25.4	6.53	4.82
P+Rh	S	8.95	5.10	5.10	5.15	3.80	3.85	3.85	0.85	0.63	FL	150.4	58.2	58.0	58.2	45.0	45.2	45.4	9.82	7.25
	R	5.75	3.85	3.90	3.90	3.10	3.10	3.15	0.69	0.51	FR	110.2	40.0	40.2	40.2	30.6	30.6	30.6	9.31	6.87
P+Mi	S	5.10	3.85	3.90	3.80	3.20	3.25	3.15	0.51	0.38	FL	58.8	37.6	38.6	37.0	32.8	33.8	32.4	5.77	4.26
	R	3.45	3.10	3.20	3.10	2.55	2.55	2.50	0.41	0.30	FR	35.8	21.2	21.6	20.8	18.6	19.0	18.2	2.91	2.15
P+Rh+Mi	S	7.20	4.40	4.55	4.30	3.50	3.65	3.40	0.61	0.45	FL	70.2	40.2	42.2	39.4	33.8	33.2	33.4	5.92	4.37
	R	4.00	3.55	3.65	3.50	2.75	2.80	2.70	0.38	0.28	FR	45.4	24.8	26.2	23.6	21.2	22.0	20.4	3.92	2.89
P+Mj	S	5.45	4.05	4.10	4.05	3.35	3.35	3.30	0.47	0.35	FL	70.4	44.6	45.6	43.8	38.0	38.8	37.4	5.57	4.11
	R	3.85	3.30	3.30	3.25	2.65	2.65	2.60	0.43	0.32	FR	48.0	27.6	28.2	27.2	23.4	23.8	23.2	3.79	2.80
P+Rh+Mj	S	8.15	4.75	4.85	4.65	3.75	3.85	3.75	0.92	0.68	FL	98.2	48.8	50.0	47.2	39.6	40.8	38.6	6.21	4.58
	R	4.50	3.80	3.85	3.75	2.90	2.95	2.90	0.80	0.59	FR	67.2	30.8	34.8	32.6	27.2	28.2	26.4	4.30	3.17
L.S.D.																				
0.01	S	0.94	0.44	0.40	0.45	0.34	0.38	0.34			FL	6.30	4.32	4.49	4.21	4.28	4.32	3.93		
	R	0.63	0.42	0.40	0.37	0.29	0.26	0.23			FR	5.40	2.92	3.04	2.99	2.55	2.63	1.36		
0.05	S	0.69	0.32	0.29	0.33	0.25	0.28	0.25			FL	4.62	3.17	3.29	3.09	3.14	3.17	2.88		
	R	0.46	0.31	0.29	0.27	0.21	0.19	0.17			FR	3.96	2.14	2.23	2.19	1.87	1.93	1.95		

S = Shoot, R = Root

Each value is mean of five replicates.

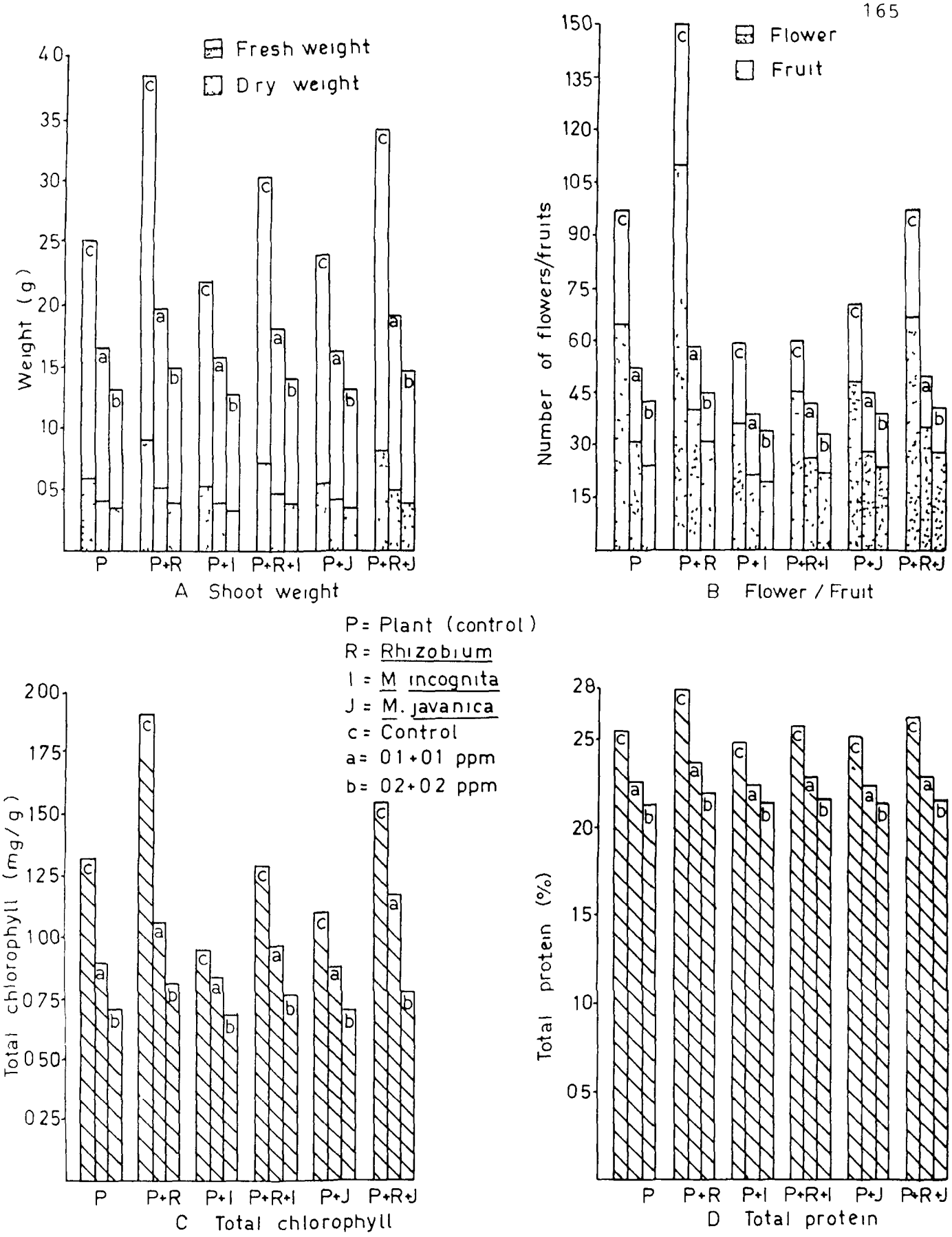

Fig 3 Interactive effects of SO_2-O_3 mixture, root-knot nematodes and root nodule bacteria on some parameters of chick-pea in simultaneous inoculation exposure

nematodes were smaller than the nematode and Rhizobium inoculated unexposed plants. These parameters were also smaller than the exposed plants inoculated with Rhizobium and were affected variously in comparison to the exposed plants without any inoculation. In relation to exposure of pollutants and nematode inoculation timing, plant growth and yield parameters were highest in simultaneous inoculation exposure and lowest in post-inoculation exposure (Tables 20 and 21, Figs. 3A and 3B).

Root-knot disease and root nodulation

Like suppressive effects of SO_2 and O_3 alone, their mixture also adversely affected root nodulation and root-knot disease on chick-pea. The adverse effect of 0.2 ppm mixture was greater than the mixture of 0.1 ppm of each of the gases. The number of galls and eggmasses of M. incognita and M. javanica were reduced. Rhizobium alone also caused reduction in root galling and eggmass production of M. incognita and M. javanica. When the plants inoculated with either species of Meloidogyne and Rhizobium were exposed, the number of galls and eggmasses were reduced in comparison to the unexposed plants inoculated with both the organisms or to the exposed plants inoculated with root-knot nematode alone. The reduction in number of galls and eggmass was highest in simultaneous inoculation exposure and lowest in post-inoculation exposure (Table 22).

Table 22. Interactive effects of mixtures of SO_2 and O_3, root-knot nematodes and root nodule bacteria on root galling, eggmass production and root nodulation on chick-pea.

Treatment		Gall/Eggmasses C	0.1+0.1 ppm Pe	0.1+0.1 ppm S	0.1+0.1 ppm Pt	0.2+0.2 ppm Pe	0.2+0.2 ppm S	0.2+0.2 ppm Pt	L.S.D. 0.01	L.S.D. 0.05	Nodule C	0.1+0.1 ppm Pe	0.1+0.1 ppm S	0.1+0.1 ppm Pt	0.2+0.2 ppm Pe	0.2+0.2 ppm S	0.2+0.2 ppm Pt	L.S.D. 0.01	L.S.D. 0.05
P																			
P+Rh											T 140.4	54.2	54.6	54.8	38.4	38.4	38.8	7.94	5.84
											F 120.6	40.6	40.6	40.8	28.0	28.2	28.4	7.01	5.17
											I -	-	-	-	-	-	-	-	-
P+Mi	G	176.2	94.2	76.4	98.4	72.4	58.0	75.2	9.01	6.65									
	E	108.6	26.2	21.4	27.4	18.2	14.4	18.2	5.79	4.27									
P+Rh+Mi	G	125.6	68.6	55.0	71.2	52.8	42.4	54.2	7.97	5.88	T 100.2	39.4	44.6	36.2	29.2	32.2	26.4	8.47	6.25
	E	96.4	18.4	15.6	19.2	13.2	10.4	13.2	5.68	4.19	F 70.8	27.0	31.2	24.4	20.2	23.2	18.0	7.20	5.31
											I 15.2	6.2	4.2	5.0	5.6	3.8	4.2	1.72	1.27
P+Mj	G	83.4	53.6	42.4	55.2	41.2	33.2	43.2	5.60	4.13									
	E	48.6	16.2	13.4	17.2	11.4	9.8	11.6	4.95	3.65									
P+Rh+Mj	G	52.2	33.8	26.2	35.4	26.4	20.4	27.6	4.39	3.24	T 125.4	46.4	50.2	44.0	33.6	37.2	31.8	8.63	6.37
	E	33.8	11.2	9.4	11.2	7.4	6.2	7.2	2.98	2.20	F 100.6	33.6	37.2	31.4	24.0	27.2	22.4	8.39	6.19
											I 11.2	4.2	2.6	3.4	2.2	0.8	1.2	1.33	0.98
L.S.D.																			
0.01	G	8.05	6.35	5.78	5.96	5.89	5.86	5.65			T 18.46	6.08	6.31	6.39	5.31	5.70	5.43		
	E	7.40	2.71	2.27	2.23	2.27	2.57	2.31			F 13.30	4.73	4.60	4.87	4.00	3.90	3.70		
											I 3.17	0.80	0.56	0.53	0.60	0.35	0.32		
0.05	G	5.74	4.53	4.12	4.25	4.20	4.18	4.03			T 12.69	4.18	4.34	4.39	3.65	3.92	3.73		
	E	5.28	1.93	1.62	1.59	1.62	1.83	1.65			F 9.14	3.25	3.16	3.35	2.75	2.68	2.54		
											I 1.91	0.48	0.34	0.32	0.36	0.21	0.19		

G = Gall, E = Eggmass

T = Total, F = Functional, I = Infected

Each value is mean of five replicates.

The mixture of the pollutants significantly reduced the number of nodules. M. incognita and M. javanica both reduced the number of nodules and also infected some nodules. The number of nodules in the exposed plants inoculated with both Rhizobium and root-knot nematodes was smaller than the unexposed plants or than the exposed plants inoculated with Rhizobium alone. The number of total and functional nodules were highest in simultaneous inoculation exposure and lowest in post-inoculation exposure. The number of nodules infected with either M. incognita or M. javanica was also significantly reduced in the plants exposed to the pollutant mixtures. The number of infected nodules was highest in pre-inoculation exposure and lowest in simultaneous inoculation (Table 22).

Leaf pigments and seed proteins

Significant reduction occurred in leaf pigments and seed proteins by exposure of plants to the mixtures of SO_2 and O_3. The reduction was greater due to the mixture of 0.2 ppm of the gases than the mixture of 0.1 ppm. Significant reductions also occurred when Rhizobium inoculated plants were exposed. But the leaf pigments and seed proteins were more than the exposed plants without Rhizobium inoculation. In the exposed plants inoculated with either species of Meloidogyne, the leaf pigments and seed proteins were

Table 23. Interactive effects of mixtures of SO_2 and O_3, root-knot nematodes and root nodule bacteria on chlorophyll content of leaves and protein contents of seeds of chick-pea.

Treatment		Chlorophyll (mg/g) C	0.1+0.1 ppm Pe	0.1+0.1 ppm S	0.1+0.1 ppm Pt	0.2+0.2 ppm Pe	0.2+0.2 ppm S	0.2+0.2 ppm Pt	L.S.D. 0.01	L.S.D. 0.05		Protein (%) C	0.1+0.1 ppm Pe	0.1+0.1 ppm S	0.1+0.1 ppm Pt	0.2+0.2 ppm Pe	0.2+0.2 ppm S	0.2+0.2 ppm Pt	L.S.D. 0.01	L.S.D. 0.05
P (Control)	A	0.621	0.419	0.419	0.420	0.334	0.335	0.335	0.081	0.060	S	11.30	9.22	9.22	9.24	8.76	8.76	8.50	0.43	0.32
	B	0.571	0.376	0.376	0.378	0.298	0.299	0.299	0.072	0.052	I	14.36	13.34	13.36	13.40	12.66	12.66	12.66	0.61	0.45
	T	1.313	0.884	0.884	0.887	0.705	0.707	0.707	0.152	0.112	T	25.66	22.56	22.58	22.64	21.42	21.42	21.46	0.95	0.70
P+Rh	A	0.943	0.495	0.497	0.498	0.336	0.377	0.379	0.106	0.078	S	12.34	9.66	9.68	9.70	9.02	9.02	9.04	0.61	0.45
	B	0.878	0.446	0.447	0.449	0.336	0.338	0.339	0.103	0.076	I	15.62	14.02	14.02	14.06	13.02	13.04	13.04	0.65	0.48
	T	1.901	1.047	1.048	1.050	0.795	0.796	0.797	0.168	0.124	T	27.96	23.68	23.70	23.76	22.02	22.06	22.08	1.48	1.09
P+Mi	A	0.447	0.387	0.396	0.382	0.315	0.323	0.311	0.053	0.039	S	10.94	9.08	9.14	9.04	8.66	8.74	8.64	0.57	0.42
	B	0.412	0.347	0.355	0.342	0.281	0.258	0.277	0.065	0.048	I	13.96	13.16	13.24	13.12	12.58	12.62	12.52	0.56	0.41
	T	0.945	0.816	0.835	0.805	0.655	0.681	0.646	0.119	0.088	T	24.90	22.24	22.38	22.16	21.24	21.36	21.16	0.92	0.68
P+Rh+Mi	A	0.612	0.440	0.454	0.426	0.343	0.457	0.332	0.094	0.069	S	11.40	9.24	9.30	9.22	8.76	8.80	8.74	0.46	0.34
	B	0.559	0.395	0.406	0.383	0.306	0.319	0.292	0.061	0.045	I	14.38	13.44	13.48	13.40	12.74	12.80	12.70	0.56	0.41
	T	1.285	0.928	0.957	0.902	0.723	0.753	0.701	0.165	0.122	T	25.78	22.67	22.78	22.62	21.50	21.60	21.44	0.96	0.71
P+Mj	A	0.520	0.409	0.413	0.407	0.330	0.332	0.329	0.076	0.056	S	11.10	9.12	9.18	9.08	8.66	8.76	8.64	0.39	0.29
	B	0.479	0.367	0.370	0.365	0.294	0.296	0.293	0.065	0.048	I	14.06	13.24	13.26	13.20	12.64	12.70	12.60	0.51	0.38
	T	1.094	0.863	0.871	0.859	0.696	0.700	0.694	0.169	0.125	T	25.16	22.36	22.44	22.28	21.30	21.46	21.24	0.99	0.73
P+Rh+Mj	A	0.729	0.467	0.479	0.460	0.360	0.376	0.359	0.085	0.063	S	11.68	9.32	9.36	9.28	8.76	8.64	8.74	0.45	0.33
	B	0.660	0.420	0.432	0.413	0.322	0.329	0.321	0.075	0.055	I	14.72	13.48	13.58	13.42	12.76	12.76	12.76	0.61	0.45
	T	1.539	0.985	1.012	0.970	0.760	0.775	0.758	0.196	0.145	T	26.40	22.80	22.94	22.70	21.52	21.60	21.44	1.12	0.83
L.S.D.																				
0.01	A	0.060	0.040	0.042	0.040	0.030	0.030	0.031			S	1.28	0.45	0.46	0.44	0.33	0.35	0.31		
	B	0.057	0.034	0.037	0.033	0.026	0.031	0.025			I	0.63	0.49	0.48	0.49	0.37	0.34	0.33		
	T	0.106	0.070	0.079	0.075	0.056	0.059	0.053			T	0.97	0.76	0.79	0.71	0.53	0.52	0.49		
0.05	A	0.044	0.029	0.031	0.029	0.022	0.022	0.023			S	0.48	0.33	0.34	0.32	0.24	0.26	0.23		
	B	0.042	0.025	0.027	0.024	0.019	0.023	0.018			I	0.46	0.36	0.35	0.36	0.27	0.25	0.24		
	T	0.078	0.051	0.058	0.055	0.045	0.043	0.039			T	0.71	0.56	0.58	0.53	0.39	0.38	0.36		

A = Chl.a, B = Chl.b, T = Total chl.

S = Soluble, I = Insoluble, T = Total

Each value is mean of five replicates.

reduced in comparison to the unexposed plants and the values were smaller than the exposed plants without nematode inoculation. When the nematode and Rhizobium inoculated plants were exposed to the mixture of SO_2 and O_3, leaf pigments and seed proteins were reduced in comparison to inoculated unexposed plants. The leaf pigments and seed proteins in exposed plants inoculated with Rhizobium and root-knot nematode were greater than the exposed plants without any inoculation and were smaller than the exposed plants inoculated with Rhizobium. The leaf pigments and seed proteins were highest in simultaneous inoculation exposure and lowest in post-inoculation exposure (Table 23, Figs. 3C and 3D).

Leaf epidermal characters

SO_2 and O_3 mixtures reduced the number of stomata, size of stomata and stomatal aperture and the number and length of trichome-hydathodes on chick-pea leaves. The adverse effect of mixture of 0.2 ppm of the gases was greater than the mixture of 0.1 ppm. In the exposed plants inoculated with Rhizobium, stomatal number and size, size of stomatal aperture and number and length of trichome-hydathodes were reduced when compared to the unexposed plants and were greater than the exposed plants without Rhizobium inoculation. In the exposed plants inoculated with root-knot nematodes, the number and size of stomata and the number of trichome-hydathodes were reduced in compari-

son to unexposed plants. The size of stomatal aperture was affected variously and length of trichome-hydathodes was reduced in the exposed plants inoculated with root-knot nematode in comparison to unexposed plant. All the leaf epidermal parameters in exposed plants inoculated with Rhizobium were smaller than the exposed plants without any inoculation. M. incognita and M. javanica separately, together with Rhizobium increased all the parameters. The size of stomatal aperture in plants inoculated with M. incognita alongwith Rhizobium, however, decreased. Number of stomata, size of stomata and stomatal aperture and the number and length of trichome-hydathodes were smaller in the exposed plants inoculated with Rhizobium and root-knot nematode in comparison to unexposed plants and to the exposed plants inoculated with Rhizobium alone. These parameters were greater than the exposed plants without any inoculation The size of stomatal aperture in exposed plants inoculated with Rhizobium together with M. incognita were, however, smaller than exposed plants without inoculations. All the measures of leaf epidermal characters were highest in simultaneous inoculation exposure and lowest in post-inoculation exposure (Tables 24, 25 and 26).

Table 24. Interactive effects of mixtures of SO_2 and O_3, root-knot nematodes and root nodule bacteria on number of stomata on leaves of chick-pea.

Treatment		Number of stomata/cm^2							
			0.1+0.1 ppm			0.2+0.2 ppm			L.S.D.
		C	Pe	S	Pt	Pe	S	Pt	0.01	0.05
P (Control)	L	24992.12	22316.27	22314.39	22315.68	21730.92	21732.28	21732.45	681.40	502.83
	U	13884.45	12179.34	12178.38	12178.62	11866.92	11867.05	11869.45	469.85	346.72
P+Rh	L	30240.45	23875.39	23876.4	23878.45	22818.32	22818.89	22820.78	721.97	532.76
	U	17160.17	13275.35	13275.48	13277.29	12580.24	12579.07	12579.68	571.70	421.88
P+Mi	L	23140.26	21456.15	21664.46	21251.80	21099.30	21306.16	20956.87	580.55	428.41
	U	12452.02	11710.91	11710.91	11489.95	11410.63	11521.41	11356.03	427.83	315.71
P+Rh+Mi	L	25916.74	22421.67	22856.00	21995.62	21732.28	22158.40	21480.80	595.83	439.68
	U	14344.72	12296.45	12413.56	11949.55	11810.00	12039.87	11671.00	539.72	398.28
P+Mj	L	23801.36	21770.14	21984.62	21664.46	21411.11	21624.16	21306.16	532.54	392.98
	U	12879.11	11767.48	11882.29	11710.91	11577.61	11691.68	11521.41	440.50	352.06
P+Rh+Mj	L	27847.42	22967.50	23413.62	22639.36	22374.61	22795.37	22158.40	568.68	419.65
	U	15352.25	12591.20	12832.87	12413.56	12098.60	12334.72	11982.27	462.98	341.65
L.S.D. 0.01	L	678.46	494.33	482.42	476.60	430.60	440.62	444.43		
	U	520.92	380.13	366.22	352.20	302.21	301.11	288.62		
0.05	L	497.46	362.45	353.72	349.45	315.72	323.07	325.86		
	U	381.95	278.72	268.52	258.24	221.59	227.38	211.62		

L = Lower surface, U = Upper surface

Each value is mean of five replicates.

Table 25. Interactive effects of mixtures of SO_2 and O_3, root-knot nematodes and root nodules bacteria on size of stomata and stomatal aperture on leaves of chick-pea.

Treatment		Size of stomata (μm^2)									Size of stomatal aperture (μm^2)								
			0.1+0.1 ppm			0.2+0.2 ppm			L.S.D.			0.1+0.1 ppm			0.2+0.2 ppm			L.S.D.	
		C	Pe	S	Pt	Pe	S	Pt	0.01	0.05	C	Pe	S	Pt	Pe	S	Pt	0.01	0.05
P (Control)	L	396.33	350.45	350.73	351.19	341.24	341.66	341.86	26.47	19.53	88.44	81.45	81.93	81.82	80.04	80.00	80.28	4.82	3.56
	U	378.45	329.14	329.09	329.62	320.45	320.72	321.07	28.02	20.68	62.50	58.24	58.41	59.71	57.27	57.34	57.55	3.59	2.65
P+Rh	L	459.74	376.87	377.04	377.27	360.22	360.42	360.94	30.91	22.81	96.81	86.10	86.19	86.44	83.09	83.24	83.59	5.14	3.79
	U	446.57	360.08	360.35	361.17	339.58	339.96	340.13	33.00	24.35	71.88	61.67	61.92	62.02	60.20	60.21	60.38	5.12	3.78
P+Mi	L	360.61	338.87	340.52	335.63	333.41	334.96	330.11	24.05	17.75	75.17	76.57	77.65	75.19	76.23	76.96	75.51	2.67	1.97
	U	340.94	314.92	316.43	311.43	309.87	311.38	308.38	29.26	21.59	53.65	54.59	55.36	53.58	54.61	55.13	54.09	2.24	1.65
P+Rh+Mi	L	402.27	357.51	360.95	352.41	347.66	350.71	343.31	26.24	19.36	81.18	79.86	81.15	78.25	78.36	79.42	77.47	2.86	2.11
	U	387.26	337.28	340.17	333.15	324.75	327.57	322.26	32.35	23.87	59.55	57.21	58.30	56.10	56.68	57.45	55.98	2.90	2.14
P+Mj	L	376.89	340.51	342.18	339.86	336.61	338.28	334.96	31.94	23.57	78.58	78.03	78.78	77.29	77.31	78.47	76.96	2.21	1.63
	U	352.69	316.43	317.96	314.92	312.90	314.43	311.38	33.05	24.39	55.31	55.63	56.16	56.10	55.67	56.22	55.13	1.94	1.43
P+Rh+Mj	L	429.65	362.65	366.13	360.25	352.77	355.53	350.04	30.73	22.68	86.59	81.93	82.88	81.02	80.43	81.37	79.42	3.71	2.74
	U	410.12	340.48	343.40	337.91	328.86	331.73	326.33	35.86	22.46	61.95	58.57	59.31	57.92	58.06	58.08	57.34	2.66	1.96
L.S.D.																			
0.01	L	29.41	20.94	23.98	20.23	17.36	15.67	18.11			7.80	4.24	4.12	4.23	3.64	3.89	3.72		
	U	31.48	23.66	21.04	21.55	17.50	18.06	17.33			6.19	5.11	5.35	5.21	4.66	4.57	4.75		
0.05	L	21.57	15.35	17.58	14.83	12.73	11.49	13.28			5.72	3.11	3.02	3.10	2.67	2.85	2.73		
	U	23.08	17.35	15.43	15.80	12.83	13.24	12.71			4.83	3.75	3.92	3.82	3.42	3.35	3.48		

L = Lower surface, U = Upper surface

Each value is mean of five replicates.

Table 26. Interactive effects of mixtures of SO_2 and O_3, root-knot nematodes and root nodule bacteria on number and length of trichome-hydathodes on leaves of chick-pea.

Treatment		Number of trichome-hydathodes/cm^2									Length of trichome-hydathodes(μm)								
			0.1+0.1 ppm			0.2+0.2 ppm			L.S.D.			0.1+0.1 ppm			0.2+0.2 ppm			L.S.D.	
		C	Pe	S	Pt	Pe	S	Pt	0.01	0.05	C	Pe	S	Pt	Pe	S	Pt	0.01	0.05
P (Control)	L	651.39	555.90	556.74	556.82	542.32	542.83	543.08	86.43	63.78	424.00	374.95	375.22	374.85	368.45	368.70	368.72	29.18	21.53
	U	411.40	344.68	345.71	345.42	337.14	337.21	337.56	61.43	45.33	404.13	351.19	351.42	352.05	345.32	342.41	345.77	31.93	23.56
P+Rh	L	1097.62	745.78	746.04	747.31	673.14	673.10	673.52	102.50	75.64	562.22	435.12	435.26	435.39	409.25	409.11	409.55	32.89	24.27
	U	828.16	476.92	477.09	477.53	431.55	431.63	431.72	87.23	64.37	545.76	414.26	414.67	414.69	390.28	390.31	390.86	28.93	21.35
P+Mi	L	457.24	492.68	506.13	479.95	498.01	507.32	476.16	30.96	22.85	365.22	357.35	360.79	353.98	356.23	359.71	352.82	25.25	18.63
	U	304.74	298.03	305.94	290.52	301,08	309.37	293.23	26.10	19.26	351.42	329.97	336.28	326.90	330.54	335.35	327.46	26.93	19.87
P+Rh+Mi	L	721.00	625.72	652.90	599.94	577.69	603.71	538.06	48.89	36.08	446.51	393.09	404.08	382.30	377.61	384.89	366.94	31.87	23.52
	U	524.72	384.46	403.84	368.96	358.29	377.43	334.28	57.69	41.57	428.83	369.57	383.36	359.59	355.33	365.53	347.05	32.41	23.92
P+Mj	L	552.03	515.50	523.75	506.13	512.10	516.98	507.21	31.79	23.46	388.90	363.23	368.63	360.79	359.71	361.47	357.96	27.71	20.45
	U	340.04	314.29	218.63	208.67	315.15	319.63	303.37	30.96	22.85	364.08	336.20	337.90	334.68	335.35	336.99	333.73	29.05	21.44
P+Rh+Mj	L	866.69	655.00	686.11	642.79	609.40	625.54	593.56	65.85	48.59	482.24	410.45	429.04	404.08	486.69	394.00	379.44	32.06	33.66
	U	782.14	421.14	426.97	398.19	381.33	396.35	386.15	47.06	34.73	460.56	383.36	388.59	378.19	363.85	370.68	357.09	36.21	26.72
L.S.D.																			
0.01	L	97.45	52.40	48.64	42.05	40.17	43.06	37.67			40.53	25.80	25.12	26.39	22.49	30.94	23.73		
	U	90.27	41.90	42.21	38.37	27.50	25.62	30.10			48.58	31.74	29.62	28.41	26.53	22.82	24.93		
0.05	L	71.45	38.42	35.66	30.83	29.45	31.57	27.62			29.72	18.92	18.42	19.35	16.82	15.35	17.40		
	U	66.19	30.72	30.95	28.13	20.16	18.78	22.07			34.89	23.27	21.72	20.83	19.45	16.73	18.28		

L = Lower surface, U = Upper surface

Each value is mean of five replicates.

Number and length of trichomes significantly increased in the exposed plants. The increase was greater due to the mixture of 0.2 ppm than 0.1 ppm of SO_2 and O_3. In the exposed plants inoculated with Rhizobium, the number and length of trichomes were greater than the unexposed and smaller than the exposed plants without Rhizobium. In the nematode inoculated plants, exposure to pollutant mixtures caused increase in number and length of trichomes and the number and length were greater than the exposed plants without nematode inoculation. The number and length of trichomes in the exposed plants inoculated with Rhizobium and root-knot nematodes were greater than unexposed plants or than exposed plants inoculated with Rhizobium alone. But number and length of trichomes were smaller than the exposed plants without inoculation of any of the organisms. The number and length of trichomes were highest in post-inoculation exposure and lowest in simultaneous inoculation exposure of plant to SO_2 - O_3 mixtures (Table 27).

Table 27. Interactive effects of mixtures of SO_2 and O_3, root-knot nematodes and root nodule bacteria on number and length of trichomes on leaves of chick-pea.

Treatment		Number of trichomes/cm^2									Length of trichomes (μm)								
			0.1+0.1 ppm			0.2+0.2 ppm			L.S.D.			0.1+0.1 ppm			0.2+0.02 ppm			L.S.D.	
		C	Pe	S	Pt	Pe	S	Pt	0.01	0.05	C	Pe	S	Pt	Pe	S	Pt	0.01	0.05
P (Control)	L	3039.57	3586.69	3585.79	3586.49	3769.07	3768.45	3768.15	153.56	113.32	371.25	367.69	366.58	366.74	374.31	374.18	374.59	21.79	18.29
	U	1651.24	1981.49	1981.40	1980.82	2080.56	3080.31	2079.97	127.04	93.75	320.75	363.58	363.50	363.19	360.01	369.84	370.18	29.88	22.05
P+Rh	L	1885.59	2676.64	2675.52	2675.81	2991.32	2991.18	2990.88	120.05	88.59	239.65	311.60	311.35	310.68	325.49	325.21	324.62	21.29	15.71
	U	988.62	1446.34	1445.73	1445.68	1611.84	1612.75	1611.59	102.77	75.84	230.11	311.93	311.62	311.30	316.25	316.11	315.89	26.37	19.46
P+Mi	L	3556.30	3873.63	3801.89	3945.36	4014.06	3951.52	4070.59	144.59	106.70	371.00	387.17	385.23	390.85	389.29	387.41	391.16	19.42	14.33
	U	2030.73	2199.45	2159.82	2239.08	2247.01	2205.46	2288.62	139.90	103.14	380.93	406.13	402.39	409.87	394.06	390.36	397.76	28.95	21.36
P+Rh+Mi	L	2694.17	3050.10	2947.20	3156.29	3430.82	3297.93	3570.69	168.52	124.36	304.10	345.69	337.05	355.32	362.13	352.19	370.76	20.60	15.20
	U	1430.09	1705.00	1636.23	1763.06	1755.47	1807.70	1990.10	124.58	92.67	322.82	356.25	346.88	365.96	358.24	348.54	368.30	26.72	19.72
P+Mj	L	3373.92	3737.33	3712.32	3766.03	3882.14	3844.45	3919.83	171.72	126.72	361.06	383.13	380.56	386.67	385.54	383.67	387.41	23.65	17.45
	U	1915.16	2102.30	2016.38	2140.01	2184.59	2163.78	2205.40	115.50	85.23	367.68	394.90	391.16	387.91	384.81	381.11	386.66	24.95	18.41
P+Rh+Mj	L	2240.28	2897.16	2833.76	2965.38	3235.12	3151.19	3321.89	161.22	118.97	384.29	333.16	328.07	338.66	348.91	341.04	355.45	19.70	11.54
	U	1212.13	1555.14	1520.84	1658.92	1776.09	1731.03	1822.34	96.62	70.56	385.02	337.52	331.49	334.41	340.54	331.40	348.35	26.78	19.77
L.S.D.																			
0.01	L	173.80	154.97	149.30	157.77	149.27	134.03	145.09			31.04	20.23	22.95	20.83	18.48	23.88	38.55		
	U	171.40	131.57	152.17	142.37	129.87	127.81	121.83			37.38	30.63	32.41	28.41	25.31	27.71	25.05		
0.05	L	127.43	113.63	109.47	115.68	109.45	98.27	106.38			22.76	14.83	16.83	15.27	13.55	15.31	15.80		
	U	125.68	96.45	111.57	104.39	95.22	93.71	98.18			27.41	22.46	23.76	20.83	18.59	20.32	18.37		

L = Lower surface, U = Upper surface

Each value is mean of five replicates.

LENTIL, Lens culinaris Medic.

SULPHUR DIOXIDE (SO_2)

Plant growth and yield

Like chick-pea, plant growth and yield characters of lentil were also significantly reduced when the lentil plants were exposed to 0.1 and 0.2 ppm concentrations of SO_2 in the exposure chambers. The higher concentration (0.2 ppm) of SO_2 caused greater reductions than the lower concentration (0.1 ppm). Rhizobium, as in chick-pea, increased the plant growth and yield in unexposed plants. The concentrations of SO_2 also caused the reductions in Rhizobium inoculated plants but these parameters in the exposed plants inoculated with Rhizobium were greater than the exposed plants without Rhizobium. M. incognita and M. javanica both suppressed plant growth and yield of lentil. M. incognita caused greater reductions than M. javanica. M. incognita reduced all the parameters significantly (either at P = 0.05 or P = 0.01). M. javanica caused significant reductions in fresh and dry weights of shoot, lengths of root and shoot and number of fruits. Reductions in the remaining parameters were not significant. Plants inoculated either with M. incognita or M. javanica when exposed to either concentration of SO_2, reductions occurred in the

Table 28. Interactive effects of SO_2, root-knot nematodes and root nodule bacteria on plant length and fresh weight of lentil.

Treatment		Length (cm)								Fresh Weight (g)							
			0.1 ppm			0.2 ppm			L.S.D.		0.1 ppm			0.2 ppm			L.S.D.	
		C	Pe	S	Pt	Pe	S	Pt	0.01	0.05	C	Pe	S	Pt	Pe	S	Pt	0.01	0.05
P (Control)	S	31.4	26.3	26.3	26.4	21.6	21.7	21.7	3.28	2.42	16.50	12.85	12.90	12.90	10.75	10.75	10.75	1.61	1.19
	R	17.0	14.5	14.5	14.5	12.4	12.4	12.4	2.48	1.83	12.50	10.40	10.40	10.40	9.25	9.25	9.30	1.56	1.15
P+Rh	S	38.7	31.4	31.5	31.5	25.4	25.4	25.5	3.24	2.39	23.75	18.00	18.05	18.05	14.65	14.60	14.65	3.26	1.67
	R	21.5	17.3	17.4	17.4	14.4	14.5	14.5	2.78	2.05	19.60	15.60	15.65	15.65	13.40	13.45	13.45	2.41	1.78
P+Mi	S	24.2	20.7	21.0	20.4	17.5	17.8	17.3	3.20	2.36	12.95	10.30	10.50	10.25	8.80	8.95	8.75	1.84	1.36
	R	13.3	11.5	11.7	11.4	10.0	10.3	9.9	1.69	1.25	8.75	7.30	7.40	7.25	6.65	6.75	6.55	1.26	0.93
P+Rh+Mi	S	27.5	2[illegible].2	24.0	22.8	19.4	20.0	19.0	3.55	2.62	16.40	12.60	13.00	12.30	10.50	10.85	10.25	2.33	1.72
	R	15.4	12.9	13.4	12.6	11.0	11.5	10.8	1.98	1.46	11.35	9.30	9.65	9.05	8.25	8.65	8.00	1.52	1.12
P+Mj	S	25.[illegible]	22.[illegible]	22.9	22.5	19.1	19.2	18.9	3.08	0.27	14.50	11.50	11.70	11.40	9.75	9.50	9.70	2.15	1.59
	R	16.5	13.9	14.0	13.9	12.0	12.0	11.9	1.73	1.28	10.45	9.00	9.20	8.85	8.10	8.35	8.00	1.40	1.03
P+Rh+Mj	S	32.[illegible]	25.[illegible]	26.7	25.6	21.6	22.1	21.2	4.12	3.04	19.85	15.10	15.70	14.70	12.50	13.00	12.20	2.93	2.16
	R	19.7	16.1	16.4	15.9	13.6	13.8	13.5	2.29	1.69	14.50	11.85	12.45	11.50	10.40	10.95	10.05	1.67	1.23
L.S.D.																			
0.01	S	2.92	3.25	2.96	2.59	2.80	2.88	2.93			1.83	1.50	1.43	1.34	1.25	1.00	1.39		
	R	1.62	1.34	1.02	1.40	1.00	0.72	1.15			1.62	1.02	1.17	1.08	0.79	0.89	0.86		
0.05	S	2.14	2.38	2.17	1.90	2.05	2.11	2.15			1.34	1.10	1.05	0.98	0.92	0.73	1.02		
	R	1.19	0.98	0.75	1.03	0.73	0.53	0.84			1.19	0.75	0.86	0.79	0.58	0.65	0.63		

C = Control, Pe = Pre-inoculation, S = Simulataneous inoculation, Pt = Post-inoculation, P = Plant, Rh = Rhizobium, Mi = Meloidogyne incognita, Mj= M. javanica (These abbreviations are common to all subsequent tables).

S = Shoot, R = Root

Each value is mean of five replicates.

Table 29. Interactive effects of SO_2, root-knot nematodes and root nodule bacteria on plant dry weight, flowering and fruiting of lentil.

Treatment		Dry weight (g)									Flower/Fruit								
		0.1 ppm			0.2 ppm			L.S.D.			0.1 ppm				0.2 ppm			L.S.D.	
	C	Pe	S	Pt	Pe	S	Pt	0.01	0.05	C	Pe	S	Pt	Pe	S	Pt	0.01	0.05
P (Control)	S 3.15	2.55	2.55	2.55	2.15	2.15	2.15	0.33	0.28	FL 52.4	31.6	31.6	31.8	27.6	27.6	27.6	3.37	2.49
	R 2.85	2.40	2.40	2.40	2.05	2.00	2.05	0.26	0.19	FR 35.8	19.4	19.4	19.4	17.0	17.0	17.2	2.95	2.18
P+Rh	S 4.65	3.70	3.70	3.75	2.90	2.95	2.95	0.50	0.37	FL 80.2	45.8	45.8	46.0	38.0	38.2	38.2	5.85	4.32
	R 4.25	3.65	3.65	3.65	2.75	2.80	2.75	0.34	0.25	FR 60.2	31.0	31.2	31.2	26.2	26.2	26.2	5.49	4.05
P+Mi	S 2.55	2.05	2.10	2.05	1.80	1.80	1.75	0.35	0.24	FL 42.2	26.0	26.4	25.8	23.4	23.8	23.2	2.94	2.17
	R 2.35	1.70	1.75	1.70	1.60	1.65	1.60	0.24	0.18	FR 26.4	15.2	15.6	14.8	13.6	13.8	13.4	2.48	1.83
P+Rh+Mi	S 3.20	2.50	2.55	2.45	2.10	2.20	2.05	0.38	0.28	FL 57.4	35.4	36.8	34.6	30.4	31.4	29.8	3.32	2.45
	R 2.15	2.20	2.30	2.15	2.00	2.10	1.95	0.23	0.17	FR 39.4	22.2	23.2	21.2	19.2	20.2	18.4	2.99	2.21
P+Mj	S 2.80	2.30	2.30	2.25	2.00	2.00	1.95	0.39	0.29	FL 47.2	29.2	29.4	29.2	25.8	26.0	25.8	3.84	2.83
	R 2.55	2.10	2.15	2.10	2.00	2.05	1.95	0.30	0.22	FR 31.4	17.8	18.0	17.8	15.8	16.0	15.6	2.91	2.15
P+Rh+Mj	S 3.90	3.00	2.10	2.90	2.55	2.60	2.45	0.50	0.37	FL 67.4	40.4	41.6	39.6	34.2	34.8	33.4	4.40	3.25
	R 3.55	2.80	2.95	2.70	2.55	2.65	2.45	0.43	0.32	FR 49.2	27.2	27.8	26.6	23.4	24.2	22.8	3.97	2.93
L.S.D.																		
0.01	S 0.46	0.37	0.38	0.33	0.30	0.29	0.22			FL 7.80	4.71	5.09	4.86	2.82	3.97	3.61		
	R 0.30	0.33	0.29	0.34	0.27	0.25	0.23			FR 4.69	2.93	2.84	2.50	2.80	2.39	2.67		
0.05	S 0.34	0.27	0.21	0.24	0.22	0.21	0.16			FL 5.72	3.45	3.73	3.56	2.80	2.91	2.65		
	R 0.22	0.24	0.21	0.25	0.20	0.18	0.17			FR 3.44	2.15	2.08	1.83	2.05	1.75	1.96		

S = Shoot, R = Root

FL = Flower, FR = Fruit

Each value is mean of five replicates.

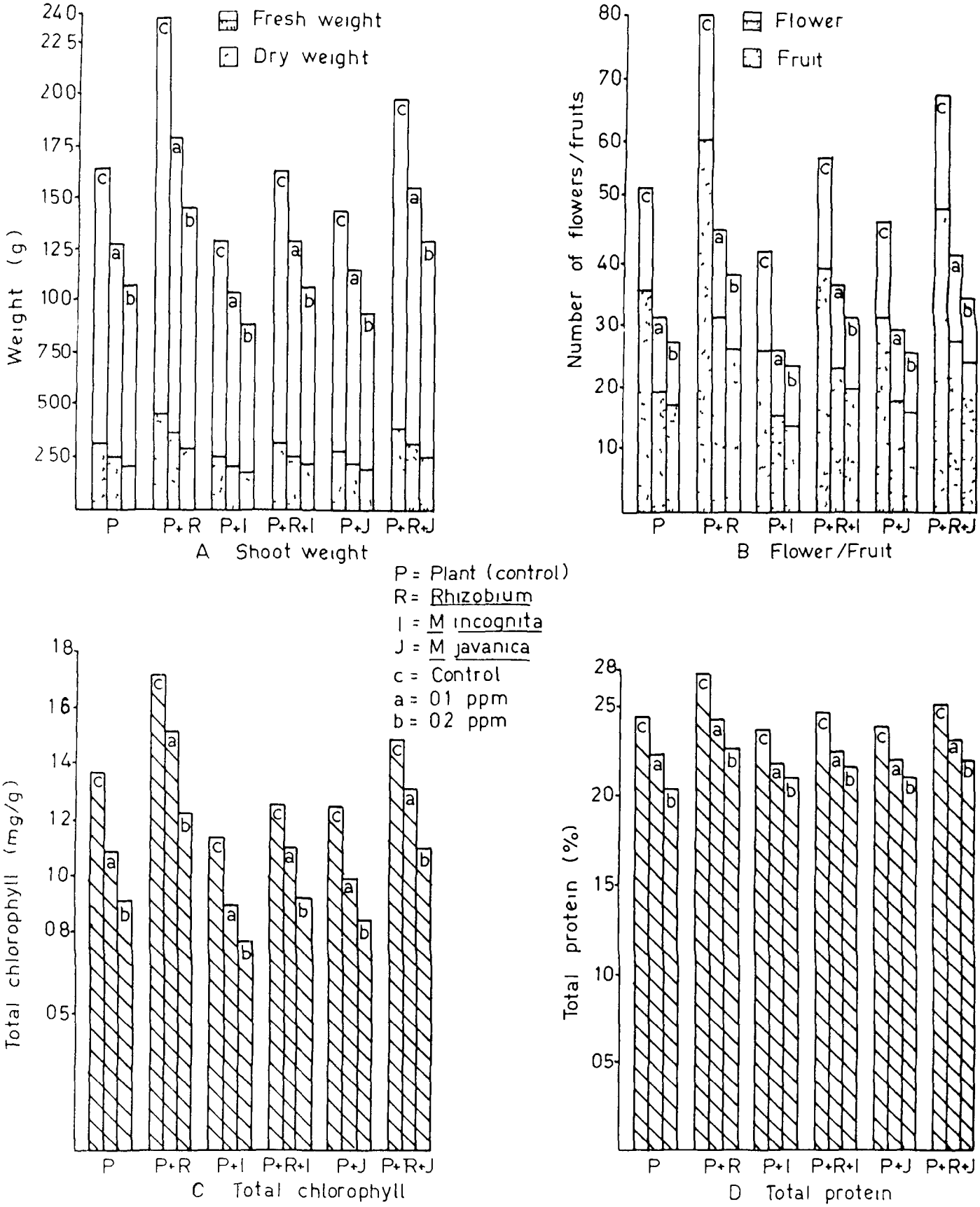

Fig 4 Interactive effects of SO_2, root-knot nematodes and root nodule bacteria on some parameters of lentil in simultaneous inoculation exposure

plant growth and yield parameters. The parameters were reduced in comparison to unexposed plants, inoculated with the either nematode. Plant growth and yield parameters in the plants inoculated with M. incognita or M. javanica together with Rhizobium were affected variously in comparison to control plants. But the reductions in growth and yield were less in comparison to plants inoculated with Rhizobium alone. Reduction in plant growth and yield of lentil also occurred when the plants inoculated with Rhizobium and either species of the nematode were exposed to the SO_2 concentrations. The parameters were smaller than exposed plants inoculated with Rhizobium and the nematode. Plant growth and yield parameters were highest in simultaneous inoculation exposures and lowest in post-inoculation exposure (Tables 28 and 29 , Figs. 4A and 4B).

Root-knot disease and root nodulation

Root-knot disease and root nodulation both were adversely affected by the SO_2 exposures of plants. Root galling, eggmass production and root nodulation were significantly suppressed. The suppression was greater due to 0.2 ppm than 0.1 ppm of SO_2. Rhizobium in unexposed plants cuased reductions in root galling and eggmass production of the nematodes. The reduction recorded in eggmass production of M. javanica was, however, not significant.

Exposures of plants inoculated with either species of Meloidogyne and Rhizobium resulted in reduction of root galling and eggmass development. Number of galls and egg-masses were less than inoculated unexposed plants or the exposed plants inoculated with root-knot nematode alone. Root galling and eggmass production were greatest in post-inoculation exposure and smallest in simultaneous inocula-tion exposure of plants. The number of galls and eggmasses in simultaneous inoculation exposure were significantly ($P = 0.01$) smaller than the pre- and post-inoculation expo-sure (Table 30).

Reduction in the number of nodules and infection of bacterial nodules were recorded due the nematode inocu-lation of lentil plants. The number of nodules in the expo-sed plants inoculated with root-knot nematodes and Rhizobium were significantly ($P = 0.01$) smaller than unexposed plants or than the exposed plants inoculated with Rhizobium. The number of nodules was highest in simultaneous inoculation exposure and lowest in post-inoculation exposure (Table 30).

Root-knot nematode infection of nodules was also reduced in the exposed plants. The number of the infected nodules was highest in pre-inoculation exposure of plants and lowest in simultaneous inoculation exposure (Table 30).

Table 30. Interactive effects of SO_2, root-knot nematodes and root nodule bacteria on root galling, eggmass production and root nodulation on lentil.

Treatment		Gall/Eggmass C	0.1 ppm Pe	0.1 ppm S	0.1 ppm Pt	0.2 ppm Pe	0.2 ppm S	0.2 ppm Pt	L.S.D. 0.01	L.S.D. 0.05		Nodule C	0.1 ppm Pe	0.1 ppm S	0.1 ppm Pt	0.2 ppm Pe	0.2 ppm S	0.2 ppm Pt	L.S.D. 0.01	L.S.D. 0.05
P																				
P+Rh											T	226.4	158.2	158.2	158.6	126.4	126.8	127.0	18.23	13.45
											F	203.2	123.2	123.6	123.8	92.8	92.8	93.2	13.36	9.86
											I	-	-	-	-	-	-	-	-	-
P+Mi	G	136.4	114.2	96.4	122.6	89.4	76.2	97.0	9.12	6.73										
	E	93.2	62.4	51.4	65.6	43.6	35.0	35.6	6.40	4.72										
P+Rh+Mi	G	107.2	94.4	78.2	99.6	73.4	62.6	97.4	8.93	6.59	T	154.6	93.2	104.6	96.4	80.4	92.6	76.2	13.31	9.82
	E	70.6	54.2	45.2	57.8	39.8	33.2	41.2	5.57	4.11	F	110.4	67.4	78.0	62.4	57.0	66.6	53.6	11.84	8.74
											I	25.8	17.2	12.6	14.6	13.4	9.8	11.2	3.20	2.36
P+Mj	G	64.4	49.2	42.4	53.8	41.8	36.4	45.6	4.63	3.42										
	E	37.8	29.2	25.4	32.4	22.4	17.2	24.6	3.51	2.59										
P+Rh+Mj	G	52.8	43.0	37.2	46.6	35.6	30.6	39.2	4.84	3.57	T	196.0	134.4	140.8	128.2	106.4	116.2	101.4	15.88	11.72
	E	34.2	27.2	23.4	29.4	19.2	15.2	20.6	3.05	2.25	F	151.4	101.8	108.2	95.0	76.4	84.8	71.8	12.77	9.42
											I	16.4	13.2	9.6	10.8	11.2	7.8	9.0	2.37	1.75
L.S.D.																				
0.01	G	12.24	8.94	9.04	8.30	5.94	5.86	6.13			T	23.77	16.66	16.75	15.95	12.18	11.94	11.97		
	E	7.89	5.22	4.36	4.56	4.00	3.67	3.86			F	24.08	12.75	12.47	12.34	10.07	10.30	10.34		
											I	4.10	3.63	2.04	2.21	1.59	1.08	1.13		
0.05	G	8.73	6.38	6.45	5.92	4.24	4.18	4.37			T	16.34	11.47	11.51	10.96	8.37	8.21	8.23		
	E	5.63	3.72	3.11	3.25	2.85	2.62	2.75			F	16.55	8.76	8.57	8.48	6.92	7.08	7.11		
											I	2.47	2.19	1.23	1.33	0.96	0.65	0.68		

G = Gall, E = Eggmass

T = Total, F = Functional, I = Infected

Each value is mean of five replicates.

Leaf pigments and seed proteins

Like chick-pea, leaf pigments and seed proteins in lentil were also reduced significantly by SO_2 exposures. The reductions were greater due to 0.2 ppm SO_2. Leaf pigments and seed proteins in the exposed plants inoculated with Rhizobium were smaller than the unexposed plants but were greater than the exposed plants without Rhizobium. Inoculation of M. incognita caused reductions in leaf pigments and seed proteins. M. javanica also caused reductions in the leaf pigments and seed proteins but the reductions in soluble protein and total proteins were not significant. Leaf pigments and seed proteins in exposed plants inoculated with root-knot nematodes were smaller than nematode inoculated unexposed plants. When the nematode and Rhizobium inoculated plants were exposed to SO_2 concentrations, the leaf pigments and seed proteins were reduced and these values in exposed plants inoculated with Rhizobium and root-knot nematode were smaller than the unexposed plants inoculated with both the organisms or the exposed plants inoculated with Rhizobium alone. Leaf pigments and seed proteins were highest in simultaneous inoculation exposure and lowest in post-inoculation exposure (Table 31, Figs. 4C and 4D).

Table 31. Interactive effects of SO_2, root-knot nematodes and root nodule bacteria on chlorophyll content of leaves and protein content of seeds of lentil.

Treatment		Chlorophyll (mg/g)									Protein (%)								
			0.1 ppm			0.2 ppm			L.S.D.				0.1 ppm			0.2 ppm			L.S.D.	
		C	Pe	S	Pt	Pe	S	Pt	0.01	0.05		C	Pe	S	Pt	Pe	S	Pt	0.01	0.05
P (Control)	A	0.724	0.574	0.576	0.576	0.479	0.482	0.485	0.092	0.068	S	10.46	9.42	9.44	9.44	8.80	8.80	8.82	0.20	0.15
	B	0.563	0.443	0.440	0.440	0.365	0.367	0.370	0.077	0.051	I	13.94	12.88	12.88	12.90	12.52	12.54	12.54	0.24	0.18
	T	1.362	1.083	1.084	1.084	0.905	0.097	0.909	0.154	0.114	T	24.40	22.30	22.32	22.34	21.32	21.34	21.36	0.57	0.42
P+Rh	A	0.902	0.802	0.802	0.800	0.652	0.652	0.654	0.099	0.077	S	11.56	10.18	10.20	10.20	9.34	9.36	9.36	0.26	0.19
	B	0.714	0.613	0.616	0.620	0.499	0.499	0.504	0.070	0.052	I	15.28	14.00	14.02	14.04	13.24	13.26	13.28	0.23	0.17
	T	1.716	1.511	1.510	1.516	1.226	1.226	1.228	0.164	0.121	T	26.84	24.18	24.22	24.24	24.58	22.62	22.64	0.47	0.35
P+Mi	A	0.594	0.463	0.470	0.459	0.397	0.403	0.394	0.068	0.050	S	10.16	9.16	9.20	9.12	8.62	8.66	8.56	0.27	0.20
	B	0.457	0.352	0.358	0.348	0.301	0.306	0.298	0.072	0.053	I	13.52	12.50	12.58	12.50	12.20	12.28	12.18	0.22	0.16
	T	1.129	0.871	0.885	0.864	0.747	0.759	0.741	0.127	0.094	T	23.68	21.66	21.78	21.62	20.82	20.94	20.74	0.51	0.38
P+Rh+Mi	A	0.648	0.562	0.581	0.549	0.471	0.486	0.459	0.084	0.062	S	10.60	9.46	9.50	9.46	8.84	8.92	8.82	0.26	0.19
	B	0.496	0.429	0.444	0.417	0.358	0.370	0.349	0.099	0.073	I	14.02	12.96	13.00	12.92	12.60	12.65	12.58	0.27	0.20
	T	1.252	1.058	1.093	1.033	0.885	0.914	0.864	0.180	0.133	T	24.62	22.42	22.50	22.38	21.44	21.58	21.40	0.51	0.38
P+Mj	A	0.664	0.515	0.525	0.511	0.439	0.445	0.435	0.080	0.059	S	10.26	9.22	9.30	9.18	8.70	8.74	8.66	0.30	0.22
	B	0.503	0.393	0.401	0.389	0.334	0.338	0.331	0.073	0.054	I	13.66	12.65	12.70	12.64	12.32	12.36	12.30	0.26	0.19
	T	1.244	0.970	0.987	0.962	0.826	0.838	0.819	0.130	0.096	T	23.92	21.88	22.00	21.82	21.02	21.10	21.96	0.54	0.40
P+Rh+Mj	A	0.788	0.672	0.689	0.656	0.559	0.580	0.546	0.079	0.058	S	10.88	9.68	9.74	9.64	9.08	9.12	9.04	0.30	0.22
	B	0.523	0.515	0.536	0.502	0.427	0.443	0.417	0.087	0.064	I	14.24	13.30	13.34	13.26	12.86	12.92	12.84	0.28	0.21
	T	1.481	1.265	1.316	1.235	1.052	1.091	1.027	0.163	0.120	T	25.12	22.98	23.08	22.90	21.96	22.04	21.88	0.43	0.32
L.S.D.																				
0.01	A	0.079	0.061	0.068	0.063	0.048	0.040	0.042			S	0.40	0.46	0.37	0.35	0.30	0.31	0.40		
	B	0.059	0.063	0.057	0.052	0.042	0.050	0.048			I	0.34	0.38	0.35	0.34	0.33	0.29	0.29		
	T	0.139	0.127	0.138	0.143	0.112	0.102	0.093			T	0.85	1.00	0.78	0.71	0.52	0.49	0.44		
0.05	A	0.058	0.045	0.050	0.046	0.035	0.029	0.031			S	0.29	0.34	0.27	0.26	0.22	0.23	0.29		
	B	0.043	0.046	0.042	0.038	0.031	0.037	0.035			I	0.25	0.28	0.26	0.25	0.24	0.31	0.21		
	T	0.102	0.093	0.101	0.105	0.082	0.075	0.068			T	0.62	0.71	0.57	0.52	0.38	0.36	0.32		

A = Chl.a, B = Chl.b, T = Total chl.

S = Soluble, I = Insoluble, T = Total

Each value is mean of five replicates.

Leaf epidermal characters

Leaf epidermal characters (stomatal count and size of stomata and stomatal aperture) were adversely affected by SO_2 exposures. The adverse effect of 0.2 ppm SO_2 was greator than 0.01 ppm. The leaf epidermal characters in Rhizobium inoculated plants exposed to SO_2 were reduced in comparison to unexposed plants but their measurements were greater than the exposed plants without Rhizobium. Root-knot nematodes caused reductions in stomatal measures. When plants inoculated with root-knot nematodes were exposed to SO_2, the number of stomata, size of stomata and stomatal aperture were smaller than the unexposed plants. The size of stomatal aperture on the upper leaf surface in plants inoculated with M. javanica in simultaneous inoculation exposure to 0.2 ppm SO_2 was, however, greater than unexposed plants. M. incognita together with Rhizobium decreased the number of stomata on lower surface and size of stomata and stomatal aperture on both the surfaces. The decrease in number of stomata on upper leaf surface was not significant. M. javanica together with Rhizobium, however, non-significantly increased the number of stomata and decreased the size of stomata and stomatal aperture. When the plants inoculated with M. incognita or M. javanica and Rhizobium were exposed to SO_2, the number of stomata and size of stomata and stomatal aperture decreased in comparison to unexposed plants or the exposed plants inoculated with Rhizobium. The number

Table 32. Interactive effects of SO_2, root-knot nematodes and root nodule bacteria on the number of stomata on leaves of lentil.

Treatment		C	0.1 ppm			0.2 ppm			L.S.D.	
			Pe	S	Pt	Pe	S	Pt	0.01	0.05
		Number of stomata/cm^2								
P (Control)	L	4936.83	4571.67	4571.14	4572.28	4446.24	4447.59	4450.10	162.10	119.62
	U	3538.06	3231.18	3234.04	3234.56	3144.42	3144.94	3145.86	134.21	99.05
P+Rh	L	5430.51	4914.24	4913.97	4914.08	4712.38	4714.45	4714.88	194.26	143.35
	U	3963.18	3505.28	3505.75	3508.45	3368.29	3365.09	3365.04	160.76	118.63
P+Mi	L	4485.03	4264.12	4312.40	4237.54	4235.80	4276.53	4195.84	170.50	125.82
	U	3173.15	2986.23	3019.72	2964.32	2966.93	2995.18	2939.20	185.86	137.15
P+Rh+Mi	L	4754.13	4460.27	4536.64	4401.84	4341.70	4426.21	4258.78	198.76	146.67
	U	3458.73	3150.48	3225.07	3112.53	3100.--	3144.94	3056.77	170.03	125.47
P+Mj	L	4613.86	4345.19	4365.94	4312.40	4318.35	4351.85	4276.50	189.39	139.75
	U	3251.89	3042.47	3056.86	3019.72	3023.98	3044.47	2995.18	145.35	107.26
P+Rh+Mj	L	5028.17	4584.17	4627.90	4528.01	4490.78	4569.45	4404.83	229.47	169.33
	U	3659.08	3255.45	3286.12	3216.05	3190.30	3227.14	3144.94	139.38	102.85
L.S.D.										
0.01	L	228.43	160.09	171.11	142.28	149.44	151.16	133.02		
	U	176.70	134.30	146.66	127.82	122.77	127.62	118.08		
0.05	L	167.49	117.38	125.46	104.32	109.57	110.83	97.53		
	U	129.56	98.47	107.53	93.72	90.02	93.57	86.58		

L = Lower surface, U = Upper surface

Each value is mean of five replicates.

Table 33. Interactive effects of SO_2, root-knot nematodes and root nodule bacteria on size of stomata and stomatal aperture on leaves of lentil.

Treatment		Size of stomata (μm^2)								Size of stomatal aperture (μm^2)							
		C	0.1 ppm			0.2 ppm			L.S.D.		C	0.1 ppm			0.2 ppm			L.S.D.	
			Pe	S	Pt	Pe	S	Pt	0.01	0.05		Pe	S	Pt	Pe	S	Pt	0.01	0.05
P (Control)	L	590.44	587.14	537.60	588.29	576.19	576.80	577.58	34.50	25.46	86.44	83.29	83.12	83.18	81.53	81.55	81.62	4.01	2.96
	U	691.12	516.19	516.26	518.58	507.58	507.40	508.02	28.01	20.67	69.50	66.22	66.17	66.19	64.92	64.93	65.08	2.97	2.19
P+Rh	L	713.28	621.39	622.28	622.56	602.48	602.76	303.24	43.07	31.78	92.49	87.96	88.10	88.24	85.49	81.62	85.08	4.40	3.25
	U	656.14	653.84	654.98	555.09	537.18	537.84	537.92	33.69	24.86	75.37	70.76	70.80	71.14	68.94	68.83	68.92	3.33	2.46
P+Mi	L	582.91	532.29	533.59	528.88	534.08	539.07	528.18	31.78	23.45	77.18	76.25	76.96	75.56	76.21	76.93	75.51	2.19	2.15
	U	517.62	465.94	471.47	463.02	467.65	572.00	463.38	30.37	22.41	60.56	59.88	60.43	59.35	59.89	60.40	59.30	2.40	1.77
P+Rh+Mi	L	603.14	548.20	557.44	544.75	547.43	555.24	542.41	34.38	25.32	80.26	78.16	79.27	77.45	77.74	78.25	77.02	2.81	2.07
	U	543.87	484.58	492.69	479.22	484.02	490.88	478.21	28.36	20.93	63.39	61.56	62.37	61.01	61.34	62.21	60.78	2.49	1.83
P+Ni	L	594.98	543.57	548.65	538.59	544.15	549.34	539.07	28.99	21.39	78.56	76.96	77.68	76.25	77.66	78.41	76.93	2.75	2.03
	U	527.79	473.63	478.02	469.33	474.20	478.68	469.81	28.95	21.36	61.74	60.71	61.27	60.16	61.25	61.84	60.68	2.08	1.52
P+Rh+Mi	L	636.64	565.31	573.34	560.13	563.20	571.31	555.24	30.95	22.84	82.49	79.65	80.79	78.69	79.99	81.16	79.24	2.95	2.18
	U	575.29	502.05	509.09	495.61	595.49	502.61	488.01	34.49	25.45	66.14	62.83	63.72	62.08	63.21	64.00	65.54	2.53	1.87
L. S. D.																			
0.01	L	46.47	35.23	33.77	29.43	33.18	33.11	30.63			7.45	7.06	6.72	7.13	6.30	6.45	6.07		
	U	54.10	42.96	33.91	30.78	26.50	24.11	27.60			4.73	4.42	4.27	4.45	4.20	3.96	4.24		
0.05	L	34.07	25.83	24.76	21.58	24.33	24.28	22.46			5.46	5.18	4.93	5.23	4.62	4.73	4.45		
	U	39.67	31.50	24.86	22.57	19.43	17.68	20.24			3.47	3.24	3.13	3.26	3.08	2.90	3.11		

L = Lower surface, U = Upper surface

Each value is mean of five replicates.

of stomata, size of stomata and stomatal aperture were highest in simultaneous inoculation exposure and lowest in post-inoculation exposure (Tables 32 and 33).

The number and length of trichomes increased significantly in lentil plants exposed to SO_2. The increase was greater due to 0.2 ppm SO_2 than 0.01 ppm SO_2. Rhizobium increased the number and length of trichomes. Exposures of Rhizobium inoculated plants resulted in an increase in the number and length of trichomes in comparison to unexposed plants inoculated with Rhizobium. Trichomes in number and length were greater than the unexposed plants and smaller than the exposed plants without Rhizobium. M. incognita and M. javanica increased the number and length of trichomes. The increase caused by M. javanica on lower leaf surface was not significant. The number and length of trichomes were increased in the exposed plants inoculated with root-knot nematodes in comparison to the unexposed plants. M. javanica and M. incognita together with Rhizobium variously affected number and length of trichomes. When the plants inoculated with the either species of root-knot nematode, and Rhizobium were exposed, the significant increase occurred in the number and length of trichomes. The number and length of trichomes were highest in post-inoculation exposure and lowest in simultaneous inoculation exposure (Table 34).

Table 34. Interactive effects of SO_2, root-knot nematodes and root nodule bacteria number and length of trichomes on leaves of lentil.

Treatment		Number of trichomes/cm^2								Length of trichomes (µm)							
		0.1 ppm			0.2 ppm			L.S.D.		0.1 ppm				0.1 ppm			L.S.D.
		C	Pe	S	Pt	Pe	S	Pt	0.01	0.05	C	Pe	S	Pt	Pe	S	Pt	0.01	0.05
P (Control)	L	2591.84	2980.62	2982.53	2984.26	3110.21	3111.82	3110.68	154.96	114.35	733.17	784.49	784.15	785.23	799.16	798.24	799.52	32.57	24.04
	U	1548.53	1811.78	1811.46	1816.24	1889.21	1890.40	1889.86	141.45	104.38	680.16	737.97	736.62	737.58	751.58	751.28	752.42	29.49	21.76
P+Rr	L	1963.52	2365.57	2364.87	2365.82	2570.42	2573.82	2568.24	122.87	90.67	591.26	559.24	559.03	559.94	688.93	688.48	689.84	27.73	20.46
	U	1082.87	1362.24	1364.29	1361.42	1487.56	1487.34	1488.24	114.67	84.62	507.58	595.14	595.32	596.10	626.31	627.24	626.88	31.24	23.05
P+Mi	L	2901.94	3219.07	3189.26	3278.68	3312.37	3281.27	3343.47	171.41	126.49	784.59	825.28	819.01	831.56	823.13	819.13	831.12	34.12	25.18
	U	1773.05	2011.08	1992.96	2029.19	2040.34	2021.45	2059.24	126.75	93.53	741.37	787.41	782.25	793.32	785.40	781.84	792.91	31.43	23.19
P+Rr+Mi	L	2545.07	3065.78	2860.32	2994.23	3038.87	2982.97	3091.81	170.45	125.78	694.23	757.14	744.55	769.96	765.70	754.92	780.40	28.96	21.37
	U	1453.42	1748.76	1703.38	1795.75	1805.61	1757.78	1855.17	101.38	74.81	633.65	696.83	686.18	708.32	707.57	697.89	721.83	27.73	20.46
P+Bj	L	2825.11	3174.36	3153.49	3204.16	3234.62	3203.51	3265.72	159.97	118.05	752.50	808.02	805.67	811.95	807.15	803.15	815.14	27.90	20.59
	U	1718.87	1953.10	1934.98	1965.78	1983.67	1964.77	2002.56	119.59	88.25	718.25	767.49	762.27	771.18	767.61	762.85	774.12	23.51	17.35
P+Rr+Mi	L	2742.15	2736.51	2549.99	2810.67	2937.30	2730.05	2915.82	138.85	102.46	630.17	702.63	688.61	712.23	720.67	704.52	741.03	26.66	19.67
	U	1282.74	1525.86	1488.45	1560.14	1586.93	1547.05	1628.10	94.40	69.66	552.56	639.57	627.27	653.54	665.62	652.01	685.07	29.72	21.93
L.S.D.																			
0.01	L	172.99	175.11	170.81	157.08	143.83	139.09	134.44			56.04	58.41	58.86	54.90	54.32	45.34	51.23		
	U	169.49	165.68	158.98	161.37	170.82	161.85	174.33			40.11	42.98	39.93	29.13	37.37	34.53	37.68		
0.05	L	126.84	129.39	125.24	115.12	105.46	101.98	98.57			41.09	42.83	43.16	40.25	39.83	35.25	37.56		
	U	124.27	121.48	116.57	118.32	125.25	118.67	127.82			29.41	31.51	29.28	21.36	27.40	25.32	27.63		

L = Lower surface, U = Upper surface.

Each value is mean of five replicates.

OZONE (O_3)

Plant growth and yield

Like SO_2, O_3 also induced reductions in plant growth and yield characters of lentil. The reductions were greater due to 0.2 ppm O_3 than 0.1 ppm. Plant growth and yield parameters in the exposed plants inoculated with Rhizobium were smaller than the unexposed plants but were greater than exposed control plants. Plant growth and yield parameters in O_3 exposed plants inoculated with either species of Meloidogyne were significantly smaller than the unexposed plants. These parameters were also smaller than the exposed uninoculated plants. Plant growth and yield parameters in exposed plants inoculated with Rhizobium and root-knot nematodes were also smaller than the unexposed plants inoculated with both the organisms and to the exposed plants with Rhizobium. Plant growth and yield parameters were greatest in simultaneous inoculation exposure and smallest in post-inoculation exposure (Tables 35 and 36; Figs. 5A and 5B).

Root-knot disease and root nodulation

O_3 exposures inhibited root-knot disease and root nodulation on lentil roots. The number of galls and eggmasses were reduced by both the concentrations; being greater

Table 35. Interactive effects of O_3, root-knot nematodes and root nodule bacteria on plant length and fresh weight of lentil.

Treatment		Length (cm)								Fresh weight (g)								
		0.1 ppm			0.2 ppm			L.S.D.		0.1 ppm				0.2 ppm			L.S.D.	
	C	Pe	S	Pt	Pe	S	Pt	0.01	0.05	C	Pe	S	Pt	Pe	S	Pt	0.01	0.05
P (Control)	S 31.4	24.2	24.2	24.2	17.0	17.0	17.0	3.33	2.46	16.50	11.50	11.55	11.55	8.10	8.10	8.10	1.96	1.45
	R 17.0	13.6	13.6	13.6	9.7	9.7	9.7	1.84	1.36	12.50	9.25	9.25	9.30	6.75	6.70	6.75	1.61	1.19
P+Rh	S 38.7	28.2	28.6	28.6	19.6	19.8	19.8	4.12	3.04	23.75	14.65	14.75	14.75	9.80	9.85	9.85	2.95	2.18
	R 21.5	16.2	16.2	16.3	11.2	11.3	11.3	1.78	1.31	19.60	12.80	12.80	12.80	8.80	8.80	8.85	2.98	2.20
P+Mi	S 24.2	20.2	20.5	19.9	14.8	15.1	14.6	2.95	2.18	12.95	9.80	9.95	9.60	7.10	7.20	6.95	1.49	1.10
	R 13.0	11.5	11.7	11.3	8.5	8.7	8.4	1.54	1.14	8.75	7.10	7.25	7.00	5.45	5.55	5.35	1.18	0.87
P+Rh+Mi	S 27.5	21.8	22.6	21.5	15.8	16.4	15.6	3.78	2.79	16.40	11.15	11.55	10.85	7.80	8.10	7.60	1.67	1.23
	R 15.0	12.3	12.8	12.1	9.0	9.3	8.8	1.61	1.19	11.35	8.55	8.85	8.35	6.30	6.55	6.15	1.19	0.88
P+Mj	S 26.8	21.7	22.0	21.6	15.8	16.0	15.6	3.63	2.68	14.50	10.80	10.90	10.70	7.70	7.80	7.65	1.69	1.25
	R 16.5	13.1	13.2	13.0	9.5	9.5	9.4	1.59	1.17	10.45	8.40	8.55	8.25	6.30	6.45	6.20	1.26	0.93
P+Rh+Mj	S 32.4	23.9	24.7	23.5	17.0	17.6	16.7	3.47	2.56	19.85	12.95	13.40	12.60	8.95	9.20	8.70	2.39	1.76
	R 19.7	14.6	14.8	14.4	10.2	10.4	10.1	1.65	1.22	14.50	10.25	10.65	9.90	7.45	7.70	7.30	1.53	1.13
L.S.D.																		
0.01	S 2.92	2.45	3.22	2.18	1.88	1.17	1.79			1.24	1.51	1.47	1.45	1.02	1.06	0.90		
	R 1.62	1.25	1.30	1.17	1.02	0.93	0.91			1.61	1.17	1.17	1.20	0.93	0.83	0.86		
0.05	S 2.14	1.78	1.63	1.60	1.38	1.25	1.31			1.34	1.11	1.08	1.06	0.75	0.78	0.66		
	R 1.19	0.92	0.95	0.86	0.75	0.68	0.67			1.19	0.86	0.86	0.88	0.68	0.61	0.63		

C = Control, Pe = Pre-inoculation, S = Simultaneous inoculation, Pt = Post-inoculation, P = Plant, Rh = Rhizobium, Mi = Meloidogyne incognita, Mj = M. javanica (These abbreviations are common to all subsequent tables)

S = Shoot, R = Root

Each value is mean of five replicates.

Table 36. Interactive effects of O_3, root-knot nematodes and root nodule bacteria on dry weight, flowering and fruiting of lentil.

Treatment		Dry weight (g)								Flower/Fruit								
			0.1 ppm			0.2 ppm			L.S.D.			0.1 ppm			0.02 ppm			L.S.D.	
		C	Pe	S	Pt	Pe	S	Pt	0.01	0.05	C	Pe	S	Pt	Pe	S	Pt	0.01	0.05
P (Control)	S	3.15	2.35	2.35	2.35	1.70	1.70	1.70	0.66	0.49	FL 52.4	26.6	26.6	26.6	23.6	23.6	23.4	4.95	3.65
	R	2.85	2.30	2.30	2.30	1.70	1.70	1.70	0.42	0.31	FR 35.8	17.2	17.2	17.4	14.6	14.8	14.8	3.58	2.64
P+Rh	S	4.65	3.00	3.00	3.05	2.00	2.05	2.05	0.84	0.62	FL 80.2	36.2	36.2	36.2	29.2	29.2	29.4	6.55	4.83
	R	4.25	3.10	3.15	3.15	2.20	2.25	2.25	0.62	0.46	FR 60.2	25.4	25.6	25.6	20.0	20.0	20.0	5.11	3.77
P+Mi	S	2.55	2.00	2.05	2.00	1.50	1.50	1.45	0.45	0.33	FL 42.2	23.2	23.6	23.0	21.2	21.6	20.8	4.68	3.45
	R	2.35	1.75	1.80	1.75	1.40	1.40	1.35	0.35	0.26	FR 26.4	14.4	14.6	14.2	13.0	13.2	12.8	2.91	2.15
P+Rh+Mi	S	3.25	2.30	2.35	2.20	1.65	1.70	1.60	0.56	0.41	FL 57.4	29.2	30.4	28.2	24.8	25.8	24.0	5.04	3.72
	R	3.15	2.10	2.20	2.05	1.60	1.65	1.55	0.33	0.24	FR 39.4	19.8	20.6	18.8	16.6	16.8	15.6	3.56	2.63
P+Vg	S	2.80	2.20	2.20	2.20	1.60	1.60	1.60	0.54	0.40	FL 47.2	25.2	25.4	25.0	22.6	22.8	22.4	4.31	3.18
	R	2.55	2.10	2.10	2.05	1.60	1.65	1.55	0.37	0.27	FR 31.4	16.0	16.2	16.0	14.2	14.4	14.2	3.33	2.46
P+Rh+Vg	S	3.90	2.65	2.75	2.60	1.85	1.90	1.80	0.72	0.53	FL 67.4	32.0	33.2	31.2	27.0	27.6	26.4	4.46	3.29
	R	3.55	2.55	2.60	2.45	1.90	1.95	1.80	0.34	0.25	FR 49.2	22.8	23.6	22.2	18.2	18.6	17.6	4.26	3.14
L.S.D.																			
0.01	S	0.46	0.30	0.33	0.27	0.25	0.23	0.20			FL 7.80	4.95	4.80	4.65	2.58	2.80	2.63		
	R	0.30	0.26	0.27	0.22	0.23	0.25	0.26			FR 4.69	2.89	2.84	3.00	1.84	1.73	1.70		
0.05	S	0.34	0.22	0.24	0.20	0.18	0.17	0.15			FL 5.72	3.63	3.52	3.41	1.89	2.05	1.93		
	R	0.22	0.19	0.20	0.16	0.17	0.18	0.19			FR 3.44	2.12	2.08	2.20	1.35	1.27	1.25		

S = Shoot, R = Root

FL = Flower, FR = Fruit

Each value is mean of five replicates.

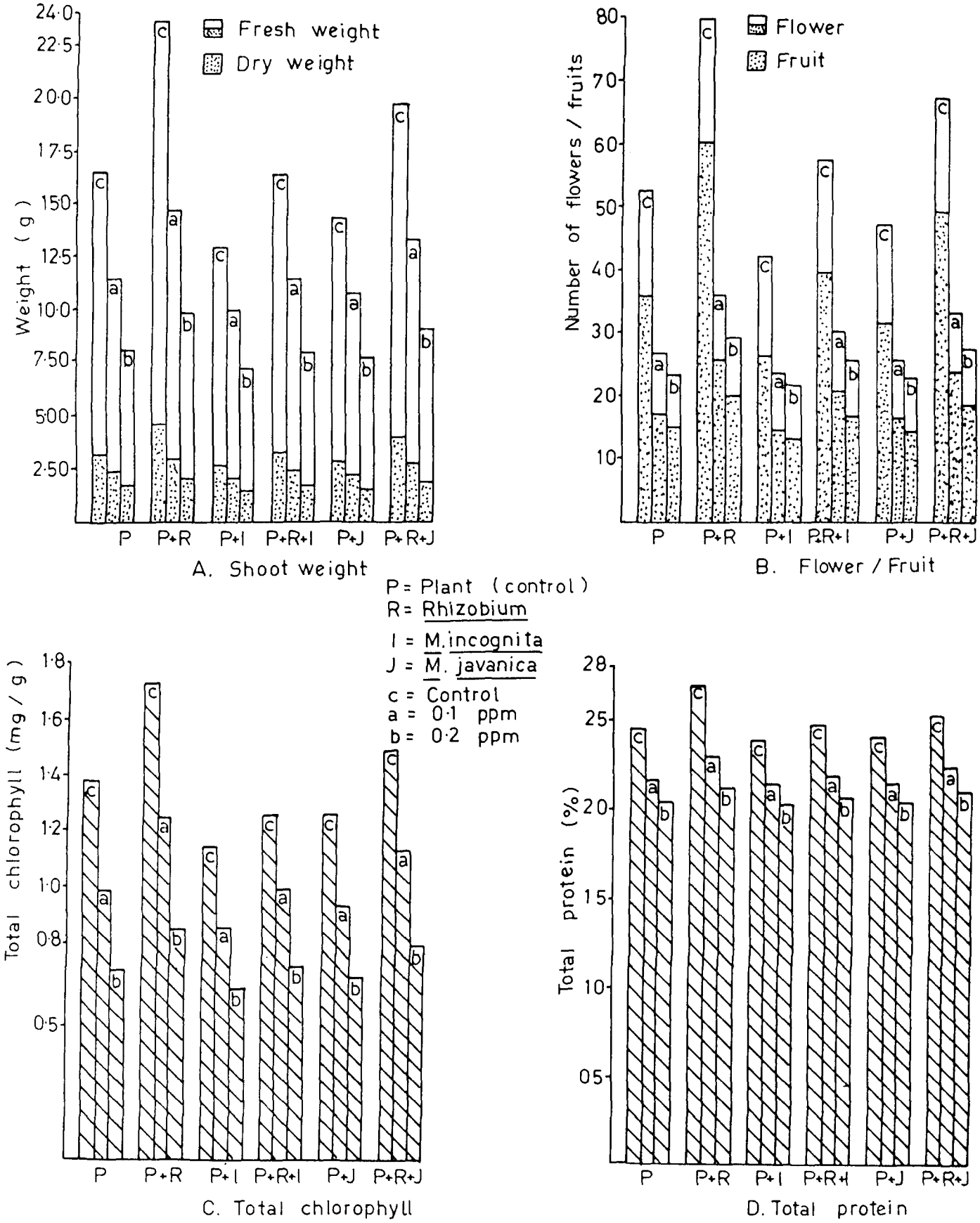

Fig.5. Interactive effects of O_3, root-knot nematodes and root nodule bacteria on some parameters of lentil in simultaneous inoculation exposure.

with 0.2 ppm. The number of galls and eggmasses in the exposed plants inoculated with both Rhizobium and M. javanica or M. incognita were comparatively less than the unexposed plants inoculated with either species of Meloidogyne and Rhizobium. The root galling and eggmass productions were also less than exposed plants inoculated with M. incognita or M. javanica alone. The number of eggmasses of M. incognita in simultaneous inoculation exposure of plants to 0.2 ppm O_3 was significant at P = 0.05 while due 0.1 ppm O_3 it was not significant. The number of galls and eggmasses were highest in post-inoculation exposure and lowest in simultaneous inoculation exposure (Table 37).

The number of root-nodules of Rhizobium were significantly reduced by O_3 exposures. The suppression was greater due to 0.2 ppm O_3. Reduction in root nodulation occurred also in plants inoculated with Rhizobium and root-knot nematode. The number of nodules in exposed plants inoculated with both Rhizobium and either species of Meloidogyne were smaller than the unexposed plants. The number of nodules (total and functional) in exposed plants inoculated with Rhizobium together with Meloidogyne spp.were less than the exposed plants inoculated with Rhizobium alone. The number of total and functional nodules were highest in simultaneuos inoculation exposure and lowest in post-inoculation exposure. O_3 exposure of plants also suppressed

Table 37. Interactive effects of O_3, root-knot nematodes and root nodule bacteria on root galling, eggmass production and root nodulation on lentil.

Treatment		Gall/Eggmass								Nodule								
			0.1 ppm			0.2 ppm			L.S.D.			0.1 ppm			0.2 ppm			L.S.D.	
		C	Pe	S	Pt	Pe	S	Pt	0.01	0.05	C	Pe	S	Pt	Pe	S	Pt	0.01	0.05
P																			
P+Rh											T 226.4	107.6	107.8	107.8	92.4	92.6	93.0	13.98	10.32
											F 203.2	80.2	80.2	80.4	66.0	66.2	66.2	11.10	8.19
											I -	-	-	-	-	-	-	-	-
P+Mi	G	136.4	77.2	65.6	84.2	60.2	50.2	66.2	10.08	7.44									
	E	93.2	35.2	28.2	36.8	24.2	19.4	26.0	4.73	3.49									
P+Rh+Mi	G	107.2	62.4	53.4	68.2	49.6	40.4	53.8	9.05	6.68	T 154.6	64.4	70.6	60.2	58.6	64.8	53.8	10.41	7.68
	E	70.6	31.4	26.2	33.6	21.2	17.4	22.6	4.21	3.11	F 110.4	46.2	52.2	42.6	40.2	45.0	36.6	8.47	6.25
											I 25.8	11.8	8.4	9.2	9.4	7.4	8.2	2.56	1.89
P+Mj	G	64.4	35.6	30.2	39.6	24.6	20.6	27.2	6.52	4.81									
	E	37.8	17.4	14.8	19.6	11.8	9.4	12.4	3.59	2.65									
P+Rh+Mj	G	52.8	28.4	23.0	31.2	22.2	19.4	24.4	5.75	4.24	T 196.0	90.4	97.4	86.2	77.2	83.2	54.0	12.67	9.35
	E	34.2	15.2	12.4	15.0	9.6	7.2	10.8	3.06	2.26	F 151.4	66.-	72.6	62.0	53.8	58.8	51.0	9.64	7.11
											I 16.4	9.2	8.8	7.6	7.4	5.6	6.2	1.54	1.14
L.S.D.																			
0.01	G	12.24	7.75	7.26	6.97	8.36	5.64	5.29			T 23.77	12.79	13.28	13.39	10.69	10.39	10.16		
	E	7.89	3.43	3.03	3.31	2.78	2.29	2.85			F 24.08	9.56	9.30	9.37	8.19	8.06	8.31		
											I 4.10	1.26	1.16	1.08	0.98	1.09	0.88		
0.05	G	8.73	5.30	5.18	4.97	3.82	4.02	3.77			T 16.34	8.79	9.13	9.20	7.35	7.14	6.98		
	E	5.63	2.45	2.16	1.36	1.98	1.63	2.03			F 16.55	6.57	6.39	6.44	5.63	5.54	5.71		
											I 2.47	0.76	0.70	0.65	0.59	0.66	0.53		

G = Gall, E = Eggmass

T = Total, F = Functional, I = Infected

Each value is mean of five replicates.

the infection of nodules by root-knot nematodes. The number of nematode infected nodules were highest in pre-inoculation exposure and lowest in simultaneous inoculation exposure (Table 37).

Leaf pigments and seed proteins

Leaf pigments and seed proteins of lentil were significantly reduced by O_3 exposures; reductions being greater by 0.2 ppm. The leaf pigments and seed proteins in exposed plants inoculated with Rhizobium were lower than the unexposed plants but were greater than the exposed plants without Rhizobium. Both M. incognita and M. javanica reduced the leaf pigment and seed protein contents. Leaf pigment and seed protein contents in the exposed plants inoculated with the root-knot nematodes were lower than the unexposed plants and the exposed plants without nematode inoculation, except the soluble proteins in plants inoculated with M. javanica and exposed to 0.2 ppm O_3. Leaf pigments and seed proteins in the exposed plants inoculated with Rhizobium and root-knot nematodes were reduced when compared to unexposed plants. Leaf pigments in the exposed plants inoculated with Rhizobium and M. incognita in pre- and post-inoculation exposure were less than the respective exposed plants without any inoculation but in simultaneous inoculation exposure were more than respective exposed plants without any organism. Seed

Table 38. Interactive effects of O_3, root-knot nematodes and root nodule bacteria on chlorophyll content of leaves and protein content of seeds of lentil.

Treatment		Chlorophyll (mg/g) C	0.1 ppm Pe	0.1 ppm S	0.1 ppm Pt	0.2 ppm Pe	0.2 ppm S	0.2 ppm Pt	L.S.D. 0.01	L.S.D. 0.05		Protein (%) C	0.1 ppm Pe	0.1 ppm S	0.1 ppm Pt	0.2 ppm Pe	0.2 ppm S	0.2 ppm Pt	L.S.D. 0.01	L.S.D. 0.05
P (Control)	A	0.724	0.513	0.513	0.513	0.307	0.363	0.363	0.092	0.068	S	10.46	8.96	8.96	8.98	8.22	8.22	8.22	0.37	0.27
	B	0.563	0.392	0.392	0.392	0.278	0.275	0.275	0.108	0.080	I	13.94	12.52	12.52	12.52	12.04	12.04	12.06	0.47	0.35
	T	1.362	0.972	0.972	0.972	0.680	0.688	0.688	0.163	0.120	T	24.40	21.48	21.48	21.50	20.26	20.26	20.28	0.89	0.66
P+Rh	A	0.902	0.650	0.654	0.654	0.441	0.441	0.443	0.072	0.053	S	11.56	9.46	9.46	9.48	8.56	8.56	8.60	0.43	0.32
	B	0.714	0.501	0.502	0.502	0.336	0.336	0.341	0.088	0.065	I	15.28	13.28	13.30	13.30	12.48	12.48	12.50	0.49	0.36
	T	1.716	1.228	1.239	1.239	0.835	0.835	0.839	0.154	0.114	T	26.84	22.74	22.76	22.78	21.04	21.06	21.10	1.07	0.79
P+Ml	A	0.594	0.436	0.445	0.429	0.320	0.325	0.314	0.065	0.048	S	10.16	8.80	8.84	8.78	8.12	8.18	8.08	0.33	0.24
	B	0.457	0.332	0.338	0.327	0.241	0.246	0.237	0.069	0.051	I	13.52	12.26	12.32	12.24	11.84	11.90	11.80	0.30	0.22
	T	1.129	0.788	0.841	0.813	0.606	0.616	0.596	0.126	0.093	T	23.68	21.06	21.16	21.02	19.6	20.08	19.88	0.76	0.56
P+Rh+Ml	A	0.648	0.496	0.517	0.484	0.351	0.373	0.342	0.076	0.056	S	10.60	8.96	8.06	8.96	8.26	8.32	8.24	0.37	0.27
	B	0.496	0.379	0.395	0.369	0.265	0.277	0.258	0.066	0.049	I	14.02	12.62	12.64	12.54	12.10	12.18	12.02	0.39	0.29
	T	1.252	0.896	0.980	0.916	0.665	0.693	0.648	0.140	0.103	T	24.62	21.58	21.70	21.50	20.36	20.50	20.26	0.79	0.58
P+[illegible]	A	[illegible]	0.480	0.485	0.476	0.346	0.349	0.343	0.085	0.063	S	10.26	8.84	8.90	8.80	8.16	8.22	8.12	0.31	0.23
	B	0.503	0.366	0.370	0.363	0.262	0.264	0.259	0.080	0.059	I	13.66	12.38	12.44	12.34	11.90	11.94	11.88	0.28	0.21
	T	1.244	0.910	0.918	0.901	0.656	0.562	0.650	0.154	0.114	T	23.92	21.22	21.34	21.14	20.06	20.16	20.00	0.69	0.51
P+Rh+Ml	A	0.788	0.574	0.594	0.560	0.400	0.401	0.390	0.089	0.051	S	10.88	9.16	9.24	9.14	8.40	8.46	8.36	0.34	0.25
	B	0.523	0.440	0.555	0.428	0.304	0.312	0.296	0.073	0.054	I	14.24	12.88	12.94	12.84	12.26	12.30	12.22	0.39	0.29
	T	1.481	1.088	1.125	1.061	0.758	0.778	0.738	0.126	0.093	T	25.12	22.04	22.18	21.98	20.66	20.76	20.58	0.85	0.63
L.S.D.																				
0.01	A	0.079	0.050	0.052	0.048	0.034	0.035	0.048			S	0.40	0.34	0.35	0.33	0.29	0.30	0.27		
	B	0.059	0.042	0.040	0.044	0.033	0.029	0.030			I	0.34	0.35	0.33	0.29	0.35	0.31	0.30		
	T	0.139	0.115	0.104	0.110	0.052	0.052	0.048			T	0.85	0.65	0.59	0.52	0.50	0.53	0.48		
0.05	A	0.058	0.037	0.038	0.035	0.025	0.026	0.028			S	0.29	0.25	0.26	0.24	0.21	0.22	0.20		
	B	0.043	0.031	0.029	0.032	0.024	0.021	0.022			I	0.25	0.26	0.24	0.31	0.24	0.23	0.22		
	T	0.102	0.084	0.076	0.081	0.038	0.038	0.035			T	0.62	0.48	0.43	0.38	0.37	0.39	0.35		

A = Chl.a, B = Chl.b, T = Total chl.

S = Soluble, I = Insoluble, T = Total

Each value is mean of five replicates.

proteins were more than respective exposed plants with out any organism. But soluble proteins in post-inoculation exposure to the 0.1 ppm O_3 and insoluble and total proteins in post-inoculation exposure to 0.2 ppm O_3 were lower than respective exposed plants without any inoculation while the total proteins in post-inoculation exposure to 0.1 ppm O_3 was equal to respective exposed plants without any inoculation. Leaf pigments and seed proteins in exposed plants inoculated with Rhizobium and M. javanica were more than the plants without any organism. Leaf pigments and seed proteins in exposed plants with Rhizobium and root-knot nematodes were lower than the exposed plants with Rhizobium. Leaf pigments and seed proteins were highest in simultaneous inoculation exposure and lowest in post-inoculation exposure (Table 38, Figs. 5C and 5D).

Leaf epidermal characters

O_3 exposures of lentil plants adversely affected the leaf epidermal characters (number of stomata and size of stomata and stomatal aperture); the effect being greater by the higher concentration. All these parameters in exposed plants inoculated with Rhizobium were reduced in comparison to Rhizobium inoculated unexposed plants. The values were, however, greater than the exposed plants without Rhizobium. In the exposed plants inoculated with M. incognita or M. javanica, the values of the parameters of epidermal charac-

Table 39. Interactive effects of O_3, root-knot nematodes and root nodule bacteria on number of stomata on leaves of lentil.

Treatment		Number of stomata/cm^2								
			0.1 ppm			0.2 ppm			L.S.D.	
		C	Pe	S	Pt	Pe	S	Pt	0.01	0.05
P (Control)	L	4936.83	4412.26	4407.88	4410.73	4283.47	4292.86	4308.77	208.31	153.72
	U	3538.06	3111.32	3103.56	3107.82	3018.98	3023.98	3033.45	160.75	118.62
P+Rh	L	5430.51	4602.49	4612.36	4629.14	4463.78	4464.61	4479.86	218.57	161.29
	U	3963.18	3315.37	3320.81	3328.67	3168.52	3175.18	3176.56	186.05	137.29
P+Mi	L	4485.03	4197.98	4238.35	4158.38	4167.86	4208.72	4127.78	160.77	118.65
	U	3173.15	2927.89	2955.77	2900.52	2907.68	2935.91	2879.98	144.27	106.46
P+Rh+Mi	L	4754.13	4357.51	4416.36	4291.45	4272.06	4334.98	4210.34	175.33	129.38
	U	3458.73	3059.64	3103.56	3016.55	2994.91	3038.66	2957.74	149.17	110.08
P+Mj	L	4613.66	4238.35	4271.21	4197.98	4208.72	4229.45	4186.10	145.34	107.25
	U	3251.89	2955.77	2978.47	2927.89	2935.91	2950.23	2921.72	167,48	123.59
P+Rh+Mj	L	5028.17	4416.36	4484.77	4349.11	4356.03	4398.63	4313.84	169.07	124.76
	U	3577.08	3118.34	3157.17	3074.28	3038.66	3068.24	3001.37	154.69	114.15
L.S.D.										
0.01	L	228.40	185.14	174.38	176.13	150.79	161.45	165.65		
	U	176.70	142.97	147.06	163.77	130.17	140.82	119.04		
0.05	L	167.47	135.75	127.86	129.14	110.56	118.38	121.46		
	U	129.56	104.83	107.83	120.08	95.44	103.25	87.28		

L = Lower surface, U = Upper surface

Each value is mean of five replicates.

Table 40. Interactive effects of O_3, root-knot nematodes and root nodule bacteria on size of stomata and stomal aperture on leaves of lentil.

Treatment		Size of stomata (μm^2)								Size of stomatal aperture (μm^2)							
		C	0.1 ppm			0.2 ppm			L.S.D.		C	0.1 ppm			0.2 ppm			L.S.D.	
			Pe	S	Pt	Pe	S	Pt	0.01	0.05		Pe	S	Pt	Pe	S	Pt	0.01	0.05
P (Control)	L	660.44	581.76	581.89	582.14	566.14	566.90	567.05	44.57	32.89	86.44	82.30	82.32	82.37	80.73	80.79	81.94	5.14	3.79
	U	591.12	511.36	511.79	512.89	498.25	498.84	499.06	34.94	25.78	69.15	64.76	64.63	64.68	63.40	63.44	63.57	3.10	2.29
P+Rh	L	713.28	608.72	608.07	610.24	586.39	586.74	587.16	48.99	36.15	92.49	86.45	86.44	86.58	84.13	84.02	84.09	5.26	3.88
	U	656.14	538.66	539.94	539.47	521.26	521.28	522.17	41.26	30.45	75.37	68.15	68.18	68.25	66.27	66.30	66.35	3.32	2.45
P+Mi	L	582.91	543.82	549.99	533.84	534.81	539.91	529.81	34.52	25.47	77.18	76.23	76.94	75.53	76.21	76.94	75.50	4.00	2.95
	U	517.62	476.09	481.46	467.39	468.39	472.83	464.03	37.35	27.56	60.66	59.02	59.56	58.49	59.01	59.57	58.47	2.94	2.17
P+Rh+Mi	L	606.74	557.41	563.14	547.19	545.51	553.40	537.76	46.06	33.99	80.26	77.83	78.86	77.04	77.74	78.63	76.78	4.49	3.31
	U	548.37	492.75	500.72	481.41	480.57	487.76	474.24	33.46	25.12	63.39	60.49	61.35	59.77	60.48	61.12	59.64	3.25	2.40
P+Mg	L	594.98	540.37	551.54	538.78	545.10	547.73	535.91	29.58	29.21	78.56	76.94	77.66	76.23	77.68	78.28	76.94	2.95	2.18
	U	527.79	476.09	480.56	469.53	475.08	477.35	470.60	33.65	24.83	61.74	59.84	60.40	59.29	60.42	60.88	59.85	3.18	2.35
P+Rh+Mg	L	636.64	562.73	579.13	554.55	560.36	565.26	552.46	41.30	30.48	82.49	79.25	80.38	78.28	80.01	81.22	78.86	3.21	2.37
	U	575.29	495.13	502.18	485.97	490.28	495.49	483.78	31.89	23.53	66.14	61.69	62.51	60.83	61.99	62.79	61.70	4.15	3.06
L.S.D.																			
0.01	L	46.47	38.82	40.07	43.00	33.24	39.89	29.76			7.45	6.59	5.69	5.84	4.71	5.13	4.64		
	U	54.10	26.65	31.98	39.85	33.31	34.63	30.22			4.73	4.30	4.20	4.24	3.90	3.68	3.83		
0.05	L	34.07	28.46	29.38	31.53	24.37	29.25	21.82			5.46	4.83	4.17	4.28	3.45	3.73	3.40		
	U	39.67	26.86	23.45	29.22	24.42	25.39	22.16			3.47	3.15	3.08	3.11	3.86	2.70	2.81		

L = Lower surface, U = Upper surface

Each value is mean of five replicates.

ters were smaller than the nematode inoculated unexposed plants. In plants inoculated with Rhizobium and M. incognita or M. javanica exposed to O_3 concentrations, the number and size of stomata were smaller than the unexposed plants having both the organisms, the root nodule bacteria and root-knot nematode. Reduction occurred in stomatal aperture as well, but the reductions were not significant in all the treatments. The number of stomata and size of stomata and stomatal aperture were greatest in simultaneous inoculation exposure and smallest in post-inoculation exposure (Tables 39 and 40).

The number and length of trichomes significantly increased by the exposures of plants to 0.1 and 0.2 ppm O_3. The increase was greater due to 0.2 ppm O_3 than 0.1 ppm. The number and length of trichomes in exposed plants inoculated with Rhizobium were higher than the unexposed plants and were lower than exposed plants without Rhizobium. The number and length of trichomes in exposed plants with M. incognita or M. javanica were increased in comparison to unexposed plants and were also greater than exposed plants without nematode inoculation. The number of trichomes on the lower surface in Rhizobium along with M. incognita inoculated plants due to pre- and post-inoculation exposure of 0.1 and 0.2 ppm O_3 were greater than the respective

Table 41. Interactive effects of O_3, root-knot nematodes and root nodule bacteria on the number and length of trichomes on leaves of lentil.

Treatment		Number of trichomes/cm^2									Length of trichomes(μm)								
			0.1 ppm			0.2 ppm			L.S.D.			0.1 ppm			0.2 ppm			L.S.D.	
		C	Pe	S	Pt	Pe	S	Pt	0.01	0.05	C	Pe	S	Pt	Pe	S	Pt	0.01	0.05
P (Control)	L	2591.84	3032.45	3021.76	3029.89	3162.04	3152.19	3150.38	156.30	115.34	733.17	810.15	809.36	809.59	824.82	826.48	824.16	48.34	35.67
	U	1548.53	1850.49	1845.36	1840.29	1927.92	1925.81	1924.62	186.53	137.65	680.16	765.18	764.72	764.48	778.78	778.31	778.59	25.64	18.92
P+Rh	L	1963.52	2548.28	2546.68	2548.51	2725.90	2731.56	2728.77	178.43	131.67	591.26	704.48	705.13	704.96	743.08	741.56	742.31	39.91	29.45
	U	1082.87	1542.08	1544.52	1537.15	1647.79	1647.83	1645.68	150.81	111.29	507.58	659.64	660.19	659.45	695.34	695.24	694.62	42.92	31.67
P+Mi	L	2901.94	3244.72	3214.44	3275.05	3220.15	3288.53	3351.77	169.60	124.83	784.49	844.18	836.08	850.66	841.31	837.19	849.56	29.65	21.88
	U	1773.05	2007.71	1989.28	2026.29	2052.23	2033.96	2072.51	188.97	139.45	741.37	804.97	797.32	811.09	802.15	798.25	809.93	33.49	24.71
P+Rh+Mi	L	2545.63	3040.45	2976.30	3182.67	3162.04	3102.38	3207.43	143.12	105.61	694.23	796.40	781.38	810.15	801.25	789.80	812.98	53.83	39.72
	U	1453.42	1776.80	1729.81	1825.49	1866.58	1816.03	1918.99	206.90	152.68	633.65	752.31	738.26	765.18	756.74	746.03	767.71	37.06	27.35
P+Mj	L	2825.11	3199.24	3168.91	3229.56	3256.97	3225.29	3288.53	149.57	110.37	762.50	827.98	823.93	832.84	837.19	833.06	841.31	38.77	28.61
	U	1718.87	1970.78	1950.27	1989.28	2005.04	1985.76	2024.32	173.35	127.92	718.25	789.67	785.84	794.26	798.25	794.36	802.15	34.10	25.16
P+Rh+Mj	L	2242.15	2856.46	2755.58	2935.97	2960.82	2879.72	3044.93	155.64	114.85	630.17	739.26	722.74	753.70	775.17	760.79	789.96	49.99	36.89
	U	1282.74	1713.73	1668.61	1760.43	1774.37	1726.75	1823.71	184.95	136.48	552.56	698.82	683.34	712.34	732.34	718.88	846.18	39.73	29.32
L.S.D.																			
0.01	L	172.99	150.64	140.30	154.46	140.23	131.41	135.13			56.04	54.12	57.70	55.69	43.08	49.33	45.66		
	U	169.49	138.24	147.92	128.53	150.96	124.75	127.94			40.11	44.20	41.56	36.62	35.02	37.44	31.66		
0.05	L	126.84	110.45	102.87	113.25	102.82	96.35	99.08			41.09	39.68	42.31	40.83	31.59	31.17	33.48		
	U	124.27	101.36	108.46	94.23	110.68	91.47	93.81			99.41	32.41	30.47	26.85	25.68	27.45	23.21		

L = Lower surface, U = Upper surface

Each value is mean of five replicates.

exposed plants without any inoculation. The number of trichomes on the upper surface in plants inoculated with Rhizobium with M. incognita in pre- and post-inoculation exposures and on both the surfaces in simultaneous inoculation exposure was smaller than respective exposed plants without any inoculation. The number of trichomes in exposed plants inoculated with Rhizobium along with M. javanica and length of trichomes in exposed plants inoculated with Rhizobium together with either species of Meloidogyne were lower than respective exposed plants without any inoculation. The number and length of trichomes in exposed plants with Rhizobium and root-knot nematodes were greater than the exposed plants inoculated with Rhizobium. The number and length of trichomes were highest in post-inoculation exposure and lowest in simultaneous inoculation exposure (Table 41).

SULPHUR DIOXIDE AND OZONE MIXTURE (SO_2+O_3)

Plant growth and yield

Like chick-pea, plant growth and yield of lentil were also significantly reduced by the mixture of SO_2 and O_3. The reductions were greater due to the mixture of 0.2 ppm of each of SO_2 and O_3 than of 0.1 ppm. In the presence of Rhizobium, plant growth and yield parameters in exposed plants were also reduced and values were smaller

than the unexposed plants and greater than exposed plants without Rhizobium inoculation. In the nematode inoculated plants (either species) plant growth and yield were reduced by the exposures and plant growth and yield were significantly smaller than unexposed plants. The plant growth and yield parameters were also smaller than the exposed plants without inoculations. Only in plant inoculated with M. javanica, the length of root and number of flowers in simultaneous inoculation exposure to the 0.2 ppm mixture of SO_2 and O_3 were greater than exposed plants without nematode inoculation while the length of root in pre-inoculation exposure and dry weight of shoot and number of fruits in simultaneous inoculation (M. javanica) exposure to the mixture of 0.2 ppm SO_2 and O_3 were equal to the respective exposed plants without any inoculation. Plant growth and yield parameters in exposed plants inoculated with Rhizobium and either species of Meloidogyne were smaller than the unexposed plants. Plant growth and yield were also less than the exposed plants inoculated with Rhizobium alone. Plant growth and yield parameters were highest in simultaneous inoculation exposure and lowest in post-inoculation exposure (Table 42 and 43, Figs. 6A and 6B).

Table 42. Interactive effects of mixtures of SO_2 and O_3, root-knot nematodes and root nodule bacteria on plant length and fresh weight of lentil.

Treatment		Length (cm)									Fresh weight (g)								
			0.1+0.1 ppm			0.2+0.2 ppm			L.S.D.			0.1+0.1 ppm			0.2+0.2 ppm			L.S.D.	
		C	Pe	S	Pt	Pe	S	Pt	0.01	0.05	C	Pe	S	Pt	Pe	S	Pt	0.01	0.05
P (Control)	S	31.4	21.5	21.6	21.6	16.2	16.2	16.4	3.06	2.26	16.50	10.25	10.30	10.30	6.45	6.45	6.45	2.13	1.57
	R	17.0	12.4	12.4	12.5	9.2	9.3	9.3	2.47	1.82	12.50	8.35	8.35	8.40	5.20	5.20	5.20	2.25	1.66
P+Rh	S	38.7	24.5	24.6	24.6	17.6	17.8	17.8	3.28	2.42	23.75	11.90	11.95	11.95	7.15	7.20	7.20	2.56	1.89
	R	21.5	14.1	14.2	14.2	10.4	10.4	10.5	2.78	2.05	19.60	9.55	9.60	9.60	5.85	5.85	5.90	2.34	1.73
P+Mi	S	24.2	18.6	18.9	18.3	14.4	14.7	14.2	2.74	2.02	12.95	8.95	9.95	8.80	5.80	5.90	5.75	1.60	1.18
	R	13.0	10.9	11.1	10.7	8.5	8.7	8.3	1.60	1.18	8.75	6.85	7.00	6.70	4.50	4.60	4.40	1.11	0.82
P+Rh+Mi	S	27.5	19.0	20.4	19.5	15.1	15.6	14.9	2.71	2.00	16.40	10.05	10.40	9.80	6.20	6.45	6.10	1.88	1.39
	R	15.0	11.5	12.0	11.4	8.8	9.0	8.6	2.11	1.56	11.35	7.45	7.75	7.25	4.75	5.00	4.65	1.31	0.97
P+Mj	S	26.8	20.0	20.2	19.8	15.0	15.2	14.9	3.47	2.56	14.50	9.75	9.80	9.62	6.20	6.25	6.15	1.86	1.37
	R	16.5	12.1	12.2	12.1	9.2	9.2	9.1	1.92	1.42	10.45	7.70	7.85	7.60	4.90	4.95	4.85	1.53	1.13
P+Rh+Mj	S	32.4	21.5	22.2	21.1	15.9	16.5	15.7	3.63	2.68	19.85	11.10	11.40	10.80	6.80	6.95	6.65	2.40	1.77
	R	19.7	13.2	13.4	13.0	9.7	9.9	9.6	2.34	1.73	14.50	8.55	8.90	8.35	5.30	5.45	5.15	1.45	1.07
L.S.D.																			
0.01	S	2.92	2.54	2.78	2.40	1.68	1.61	1.72			1.83	1.06	0.87	0.94	0.67	0.52	0.56		
	R	1.62	1.25	1.17	1.21	0.93	0.80	0.72			1.62	0.76	0.93	0.80	0.59	0.52	0.41		
0.05	S	2.14	1.86	2.04	1.76	1.23	1.18	1.26			1.34	0.78	0.64	0.69	0.49	0.38	0.41		
	R	1.19	0.92	0.86	0.89	0.68	0.59	0.53			1.19	0.56	0.68	0.59	0.43	0.38	0.30		

C = Control, Pe = Pre-inoculation, S = Simultaneous inoculation, Pt = Post-inoculation, P = Plant, Rh = Rhizobium, Mi = Meloidogyne incognita, Mj = M. javanica (These abbreviations are common to all subsequent tables)

S = Shoot, R = Root

Each value is mean of five replicates.

Table 43. Interactive effects of mixtures of SO_2 and O_3, root-knot nematodes and root nodule bacteria on dry weight, flowering and fruiting of lentil.

Treatment		Dry weight (g)								Flower/Fruit								
			0.1+0.1 ppm			0.2+0.2 ppm			L.S.D.			0.1+0.1 ppm			0.2+0.2 ppm			L.S.D.	
		C	Pe	S	Pt	Pe	S	Pt	0.01	0.05	C	Pe	S	Pt	Pe	S	Pt	0.01	0.05
P (Control)	S	3.15	2.15	2.15	2.15	1.35	1.35	1.35	0.37	0.27	FL 52.4	24.2	24.2	24.4	21.6	21.6	21.6	4.28	3.16
	R	2.85	2.10	2.10	2.10	1.35	1.35	1.35	0.27	0.20	FR 35.8	14.6	14.6	14.6	12.6	12.6	12.6	2.24	1.65
P+Rh	S	4.65	2.50	2.50	2.55	1.55	1.55	1.55	0.56	0.41	FL 80.2	20.0	30.2	30.2	25.4	25.6	25.6	6.07	4.48
	R	4.25	2.40	2.40	2.40	1.45	1.50	1.50	0.50	0.37	FR 60.2	19.2	19.2	19.2	16.2	16.2	16.4	2.97	2.19
P+Mi	S	2.55	1.85	1.90	1.85	1.25	1.25	1.20	0.20	0.22	FL 42.2	21.6	22.0	21.4	20.2	20.4	19.8	2.78	2.05
	R	2.35	1.70	1.75	1.70	1.15	1.20	1.15	0.24	0.18	FR 26.4	12.8	13.2	12.6	11.6	11.8	11.4	2.33	1.72
P+Rh+Mi	S	3.25	2.[illegible]	2.15	2.05	1.30	1.35	1.30	0.39	0.29	FL 57.4	25.2	26.4	24.6	22.2	23.2	21.6	2.93	2.16
	R	3.15	1.85	1.95	1.80	1.20	1.30	1.20	0.37	0.27	FR 39.4	15.8	16.6	15.2	13.6	14.2	13.2	2.76	2.04
P+Mj	S	2.80	2.00	2.05	2.00	1.31	1.35	1.30	0.35	0.26	FL 47.2	23.2	23.2	23.4	21.0	21.2	20.8	2.48	1.83
	R	2.55	1.95	1.95	1.90	1.25	1.25	1.25	0.33	0.24	FR 31.4	14.0	14.2	13.8	12.4	12.6	12.4	2.26	1.67
P+Rh+Mj	S	3.90	2.30	2.35	2.25	1.45	1.50	1.40	0.28	0.21	FL 68.4	27.6	28.4	27.0	23.6	24.6	23.2	2.85	2.10
	R	3.55	2.15	2.20	2.10	1.35	1.40	1.35	0.56	0.41	FR 49.2	17.4	18.0	17.0	15.0	15.4	14.6	3.42	2.51
L.S.D.																			
0.01	S	0.46	0.25	0.18	0.22	0.15	0.18	0.15			FL 7.80	3.34	2.95	3.45	2.88	2.82	2.71		
	R	0.30	0.20	0.18	0.25	0.12	0.15	0.11			FR 4.69	1.98	1.79	1.73	1.47	1.31	1.46		
0.05	S	0.34	0.18	0.13	0.16	0.11	0.13	0.11			FL 5.72	2.45	2.16	2.53	2.11	2.07	1.99		
	R	0.22	0.15	0.13	0.18	0.09	0.11	0.08			FR 3.44	1.45	1.31	1.27	1.08	0.96	1.07		

S = Shoot, R = Root

Each value is mean of five replicates.

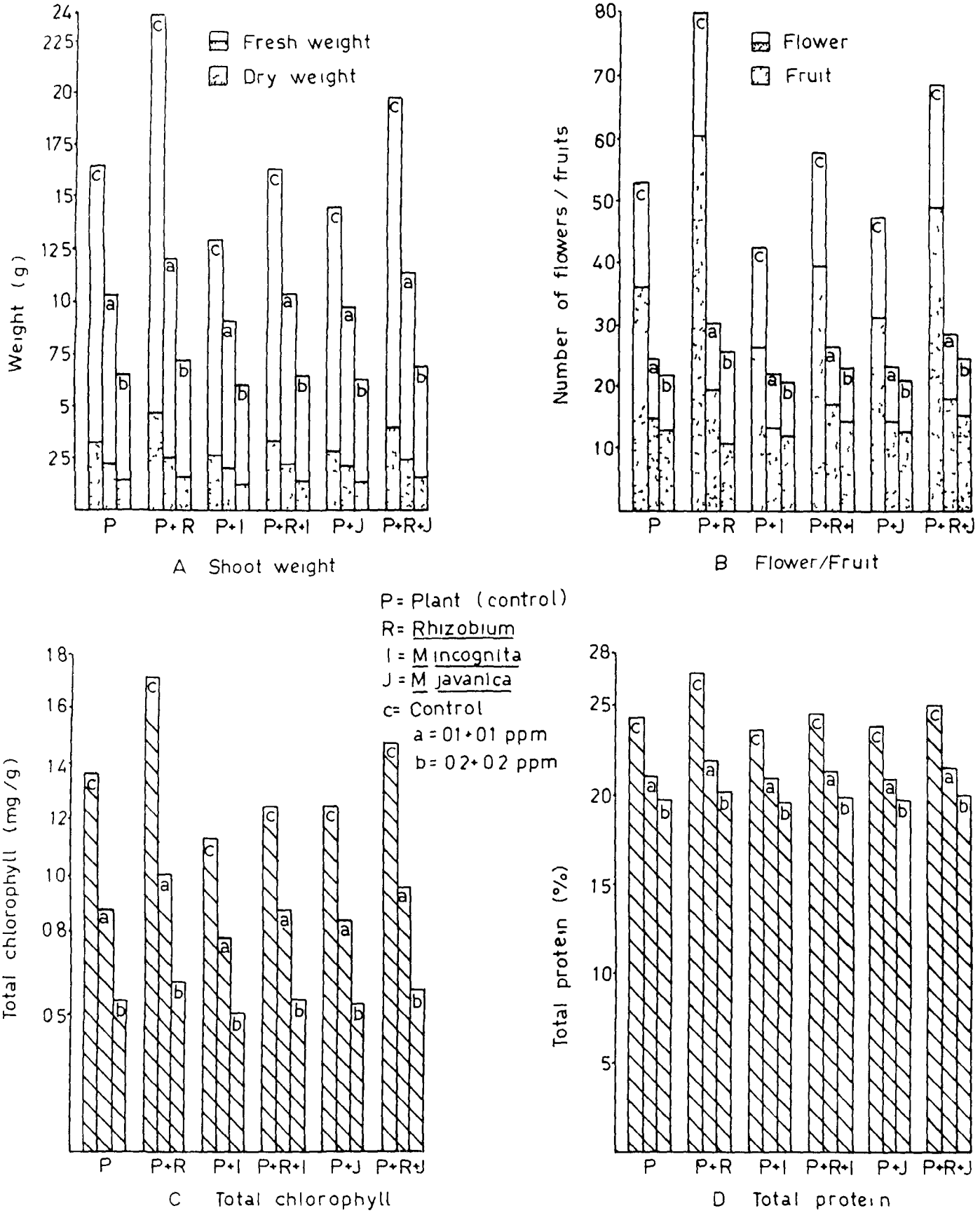

Fig6 Interactive effect of SO_2-O_3 mixture, root-knot nematodes and root nodule bacteria on some parameters of lentil in simultaneous inoculation exposure

Root-knot disease and root nodulation

The air pollutants in mixtures also suppressed root galling and eggmass productions of both the species of root-knot nematodes and root nodulation on lentil. The mixture of higher concentration (0.2 ppm SO_2 + 0.2 ppm O_3) was more effective in the suppression.

The number of galls and eggmasses of both M. incognita and M. javanica were lower in the exposed plants in comparison to unexposed plants. As observed in earlier experiments, Rhizobium inhibited root galling and eggmass production of root-knot nematodes. The number of galls and eggmasses in exposed plants added with Rhizobium was further inhibited. Their number were smaller than the unexposed plants or exposed plants inoculated with either species of Meloidogyne alone. The number of galls and eggmasses were highest in post-inoculation exposure and lowest in simultaneous inoculation exposure (Table 44).

Root nodulation was suppressed by the mixture of SO_2 and O_3. M. incognita and M. javanica also suppressed the root nodules and some were infected as well. The number of total and functional nodules and infected nodules with root-knot nematodes in exposed plants inoculated with Rhizobium together with either species of root-knot nematodes were smaller than unexposed plants with Rhizobium

Table 44. Interactive effects of mixtures of SO_2 and O_3, root-knot nematodes and root nodule bacteria on root galling, eggmass production and root nodulation on lentil.

Treatment		Gall/Eggmass								Nodule								
			0.1+0.1 ppm			0.2 ppm			L.S.D.			0.1+0.1 ppm			0.2+0.2 ppm			L.S.D.	
		C	Pe	S	Pt	Pe	S	Pt	0.01	0.05	C	Pe	S	Pt	Pe	S	Pt	0.01	0.05
P																			
P+Rh											T 226.4 F 203.2 I –	83.4 62.2 –	83.8 62.0 –	84.0 62.4 –	56.8 40.8 –	56.8 40.8 –	57.0 41.0 –	10.62 9.42 –	7.84 6.95 –
P+Mi	G	136.4	65.4	53.6	72.2	48.4	39.2	53.4	10.58	7.81									
	E	93.2	27.2	22.4	29.2	18.2	15.4	19.8	9.15	6.76									
P+Rh+Mi	G	107.2	51.2	43.6	55.8	38.6	31.8	41.4	8.29	6.12	T 154.6 F 110.4 I 25.8	52.4 36.0 9.6	58.2 41.0 7.0	59.2 33.4 7.8	36.2 25.0 5.2	41.4 29.2 3.6	35.4 22.8 4.0	6.92 6.27 3.89	5.11 4.63 2.07
	E	70.6	24.6	20.2	24.8	14.2	13.4	16.2	8.50	6.27									
P+Mj	G	64.4	30.4	25.0	33.4	20.6	17.2	23.4	6.18	4.56									
	E	37.8	11.5	10.4	13.4	8.2	6.4	9.2	2.21	1.63									
P+Rh+Mj	G	52.8	23.2	20.4	26.4	19.8	16.6	21.4	5.38	3.97	T 196.0 F 151.4 I 16.4	71.8 52.0 6.8	77.2 56.6 4.6	68.2 48.8 5.2	47.0 33.2 3.2	52.2 37.2 1.0	44.8 31.2 1.8	9.00 6.40 2.24	6.64 4.72 1.65
	E	34.2	11.6	9.2	12.6	7.4	6.2	7.8	1.88	1.39									
L.S.D.																			
0.01	G	12.24	5.96	6.08	5.90	3.97	2.43	3.55			T 23.77 F 24.08 I 4.10	9.59 7.68 1.36	9.76 7.43 0.95	9.86 7.84 0.85	6.24 5.12 0.68	5.35 4.74 0.33	5.11 4.92 0.60		
	E	7.89	3.03	2.62	2.78	1.58	1.25	1.42											
0.05	G	8.73	4.25	5.34	4.21	2.83	2.45	2.53			T 16.34 F 16.55 I 2.47	6.59 5.28 0.82	6.71 5.11 0.56	6.78 5.39 0.51	4.29 3.52 0.41	3.68 3.24 0.20	3.51 3.38 0.36		
	E	5.63	2.16	1.87	1.98	1.13	0.89	1.01											

G = Gall, E = Eggmass

T = Total, F = Functional, I= Infected

Each value is mean of five replicates.

and root-knot nematodes and the number of total and functional nodules were also smaller than the Rhizobium inoculated plants exposed to mixture of SO_2 and O_3. The number of total and functional nodules were highest in simultaneous inoculation exposure and lowest in post-inoculation exposure. The number of infected nodules with root-knot nematodes were highest in pre-inoculation exposures and lowest in simultaneous inoculation exposure (Table 44).

Leaf pigments and seed proteins

The mixture of SO_2 and O_3 significantly reduced leaf pigments and seed proteins in exposed plants of lentil. Greater reductions were caused by the mixture of 0.2 ppm of each of SO_2 and O_3 than the mixture of 0.1 ppm of each pollutant. In exposed plants inoculated with Rhizobium, leaf pigments and seed proteins were less than unexposed plants but greater than exposed plants without Rhizobium. Leaf pigments and seed proteins in root-knot nematode inoculated plants were less than the unexposed plants and the exposed plants without the nematode. Only soluble proteins in plants inoculated with M. javanica in simultaneous inoculation exposure were greater than the plants without any

Table 45. Interactive effects of mixtures of SO_2 and O_3, root-knot nematodes and root nodule bacteria on chlorophyll content of leaves and protein content of seeds of lentil.

Treatment		Chlorophyll (mg/g) C	0.1+0.1 ppm Pe	0.1+0.1 ppm S	0.1+0.1 ppm Pt	0.2+0.2 ppm Pe	0.2+0.2 ppm S	0.2+0.2 ppm Pt	L.S.D. 0.01	L.S.D. 0.05		Protein (%) C	0.1+0.1 ppm Pe	0.1+0.1 ppm S	0.1+0.1 ppm Pt	0.2+0.2 ppm Pe	0.2+0.2 ppm S	0.2+0.2 ppm Pt	L.S.D. 0.01	L.S.D. 0.05
P (Control)	A	0.724	0.465	0.463	0.465	0.293	0.293	0.296	0.087	0.064	S	10.46	8.74	8.74	8.74	7.96	7.96	7.96	0.33	0.24
	B	0.563	0.353	0.352	0.254	0.220	0.220	0.224	0.083	0.061	I	13.94	12.34	12.34	12.34	11.78	11.80	11.80	0.42	0.31
	T	1.362	0.871	0.872	0.874	0.552	0.552	0.556	0.168	0.124	T	24.40	21.08	21.08	21.08	19.74	19.76	19.76	0.80	0.59
P+Rh	A	0.902	0.535	0.535	0.538	0.326	0.327	0.328	0.079	0.058	S	11.56	9.08	9.10	9.10	8.18	8.20	8.20	0.30	0.22
	B	0.714	0.408	0.408	0.510	0.244	0.246	0.247	0.084	0.062	I	15.28	12.94	12.94	12.96	12.10	12.10	12.12	0.38	0.28
	T	1.716	1.007	1.007	1.009	0.615	0.516	0.619	0.183	0.135	T	26.84	22.02	22.04	22.06	20.28	20.30	20.32	0.85	0.63
P+Mi	A	0.594	0.404	0.411	0.397	0.265	0.270	0.263	0.098	0.072	S	10.16	8.62	8.66	8.56	7.88	7.94	7.86	0.24	0.18
	B	0.457	0.306	0.312	0.301	0.198	0.202	0.196	0.088	0.065	I	13.52	12.22	12.32	12.18	11.72	11.78	11.64	0.30	0.22
	T	1.129	0.760	0.773	0.747	0.499	0.508	0.495	0.131	0.097	T	23.67	20.84	20.98	20.76	19.60	19.72	19.50	0.53	0.39
P+Rh+Mi	A	0.648	0.451	0.467	0.440	0.283	0.292	0.278	0.065	0.048	S	10.60	8.76	8.80	8.70	7.98	8.06	7.92	0.30	0.22
	B	0.496	0.343	0.355	0.334	0.212	0.212	0.208	0.075	0.055	I	14.02	12.40	12.48	12.38	11.82	11.88	11.80	0.23	0.17
	T	1.252	0.849	0.879	0.827	0.535	0.550	0.224	0.136	0.100	T	24.62	21.16	21.28	21.08	19.80	19.94	19.72	0.57	0.42
P+Mj	A	0.664	0.437	0.441	0.433	0.282	0.285	0.280	0.069	0.051	S	10.26	8.62	8.68	8.62	7.94	7.98	7.90	0.34	0.25
	B	0.503	0.332	0.335	0.329	0.212	0.214	0.210	0.064	0.047	I	13.66	12.32	12.36	12.26	11.70	11.78	11.68	0.39	0.29
	T	1.244	0.823	0.830	0.815	0.532	0.537	0.527	0.114	0.084	T	23.92	20.94	21.04	20.88	19.64	19.76	19.58	0.79	0.58
P+Rh+Mj	A	0.788	0.497	0.510	0.484	0.309	0.315	0.381	0.076	0.056	S	10.88	8.90	8.92	8.86	8.04	8.12	8.00	0.39	0.29
	B	0.523	0.379	0.389	0.368	0.233	0.237	0.226	0.057	0.042	I	14.24	12.60	12.70	12.56	11.90	11.96	11.86	0.47	0.35
	T	1.481	0.935	0.960	0.911	0.583	0.593	0.567	0.123	0.091	T	25.12	21.50	21.60	21.42	19.94	20.08	19.86	0.94	0.69
L.S.D.																				
0.01	A	0.097	0.049	0.041	0.038	0.030	0.029	0.025			S	0.40	0.29	0.30	0.29	0.26	0.22	0.22		
	B	0.059	0.034	0.035	0.031	0.027	0.025	0.026			I	0.34	0.31	0.27	0.27	0.22	0.23	0.25		
	T	0.139	0.086	0.072	0.072	0.042	0.044	0.046			T	0.85	0.56	0.59	0.53	0.29	0.41	0.40		
0.05	A	0.058	0.036	0.030	0.028	0.022	0.021	0.018			S	0.29	0.21	0.22	0.21	0.19	0.16	0.16		
	B	0.043	0.025	0.026	0.023	0.020	0.018	0.019			I	0.25	0.23	0.20	0.20	0.16	0.17	0.18		
	T	0.102	0.065	0.053	0.053	0.031	0.032	0.029			T	0.62	0.41	0.43	0.39	0.28	0.30	0.29		

A = Chl.a, B = Chl. b, T = Total chl.

S = Soluble, I = Insoluble, T = Total

Each value is mean of five replicates.

inoculation and total proteins in the same treatment, were similar. Leaf pigments and seed proteins in exposed plants added with Rhizobium and M. incognita or M. javanica were also less than unexposed plants. The leaf pigments in simultaneous inoculation exposure (mixture of 0.1 ppm SO_2 and O_3) were, however, greater. The seed proteins in pre- and simultaneous inoculation exposure to the pollutant mixtures, the insoluble proteins in post-inoculation exposure to 0.1 ppm SO_2 and O_3 mixture were greater than respective exposed plants without any inoculation. The total proteins in post-inoculation exposure to the mixture of 0.1 ppm SO_2 and O_3 and insoluble proteins in post-inoculation exposure to 0.2 ppm SO_2 and O_3 were similar to the respective exposed plants without any inoculation. In the exposed plants inoculated with Rhizobium and M. javanica, the leaf pigments and seed proteins were greater than the respective exposed plants without any organism. The pigments and proteins in plants added with Rhizobium together with either species of root-nematodes were also less than the exposed plants inoculated with Rhizobium. The leaf pigments and seed proteins in general were highest in simultaneous inoculation exposure and lowest in post-inoculation exposure (Table 45, Figs. 6C and 6D).

Leaf epidermal characters

The response of leaf epidermal characters to

exposures of SO_2 and O_3 were similar to those observed in individual exposures of plants to the air pollutants, singly. The number of stomata and size of stomata and stomatal aperture were significantly decreased by the pollutant mixtures. The number of stomata, size of stomata and stomatal aperture in exposed plants inoculated with Rhizobium were smaller than the unexposed plants and were greater than respective exposed plants without Rhizobium. The number and size of stomata were significantly ($P = 0.01$) less in exposed plants inoculated with M. incognita or M. javanica than the unexposed plants. The size of stomatal aperture was also smaller than the unexposed plants at the various significance levels in different treatments. All these parameters were smaller than the respective exposed plants without Rhizobium or root-knot nematodes. M. incognita together with Rhizobium decreased the number of stomata and size of stomata and stomatal aperture. M. javanica together with Rhizobium increased the number of stomata but decreased the size of stomata and stomatal aperture. The number and size of stomata in exposed plants with Rhizobium together with root-knot nematodes were less than the unexposed plants. The size of stomatal aperture was also smaller than the unexposed plants in different treatments. All the parameters in exposed plants with Rhizobium alongwith M. incognita were less than the respec-

Table 46. Interactive effects of mixtures of SO_2 and O_3, root-knot nematodes and root nodule bacteria on number of stomata on leaves of lentil.

Treatment		Number of stomata/cm^2							
			0.1+0.1 ppm			0.2+0.2 ppm			L.S.D.
		C	Pe	S	Pt	Pe	S	Pt	0.01	0.05
P (Control)	L	4936.83	4345.24	4349.63	4348.62	4236.48	4237.62	4239.14	196.87	145.28
	U	3538.06	3063.26	3070.10	3065.54	2984.82	2985.70	2985.78	155.50	114.75
P+Rl	L	5430.51	4567.59	4567.11	4569.83	4372.56	4373.23	4373.67	233.75	172.49
	U	3963.18	3238.62	3247.05	3242.57	3114.53	3114.09	3115.27	177.88	131.26
P+Ml	L	4485.03	3247.05	3248.62	3251.43	4154.53	4175.00	4114.20	162.09	119.61
	U	3173.15	2917.39	2939.79	2889.87	2898.74	2912.88	2870.87	145.60	107.44
P+Rl+Ml	L	4795.13	4316.17	4374.92	4258.49	4216.85	4258.50	4155.34	166.88	123.15
	U	3458.73	3019.50	3057.38	2976.56	2956.72	2985.70	2913.93	183.73	135.58
P+Mj	L	4613.86	4222.94	4256.00	4182.34	4195.67	4229.16	4134.27	178.17	131.48
	U	3251.89	2945.44	2968.28	2917.39	2927.16	2950.30	2912.88	175.29	129.35
P+Rh+Mj	L	5028.17	4374.97	4434.75	4307.81	4300.56	4364.50	4216.95	148.74	109.76
	U	3659.08	3077.99	3116.69	3034.09	3000.34	3038.81	2971.14	174.26	128.59
L.S.D.										
0.01	L	228.43	161.37	165.67	155.50	128.01	132.91	140.76		
	U	176.70	141.20	147.10	151.50	128.64	136.17	117.92		
0.05	L	167.49	118.32	121.47	113.98	93.86	97.45	103.21		
	U	129.56	103.53	107.85	111.08	94.32	99.84	86.46		

L = Lower surface, U = Upper surface

Each value is mean of five replicates.

Table 47. Interactive effects of mixtures of SO_2 and O_3, root-knot nematodes and root nodule bacteria on size of stomata and stomatal aperture on leaves of lentil.

Treatment		Size of stomata (μm^2)									Size of stomatal aperture (μm^2)								
			0.1+0.1 ppm			0.2+0.2 ppm			L.S.D.			0.1+0.1 ppm			0.2+0.2 ppm			L.S.D.	
		C	Pe	S	Pt	Pe	S	Pt	0.01	0.05	C	Pe	S	Pt	Pe	S	Pt	0.01	0.05
P (Control)	L	660.44	578.61	569.37	569.24	564.73	564.48	565.33	30.84	22.76	86.44	81.46	81.55	81.52	79.26	79.67	79.58	4.68	3.45
	U	591.12	509.83	509.59	510.25	496.55	496.74	497.37	55.95	41.29	69.15	63.87	64.03	64.55	63.04	63.19	65.25	3.18	2.35
P+Rh	L	713.28	602.45	602.51	602.83	578.82	578.59	578.48	39.51	29.45	92.49	84.62	84.81	84.98	82.42	82.06	82.37	5.24	3.87
	U	656.14	535.21	535.07	535.68	514.83	514.13	514.92	51.02	37.65	75.37	67.12	67.23	67.65	65.41	65.56	65.76	3.96	2.90
P+Mi	L	582.91	543.97	549.13	536.42	537.60	542.77	532.53	25.31	18.68	77.18	76.21	76.93	75.51	75.87	76.60	75.16	2.76	2.04
	U	517.62	476.25	480.74	275.45	270.84	275.35	255.72	30.17	22.26	60.66	59.28	59.84	58.74	59.47	60.03	58.91	2.20	1.62
P+Rh+Mi	L	609.14	549.41	557.37	541.78	542.97	550.91	535.19	28.78	21.24	80.20	77.13	71.85	76.41	77.39	78.52	76.29	3.37	2.49
	U	548.67	485.77	492.76	479.58	477.92	484.86	460.28	33.97	25.07	63.39	61.06	61.93	60.21	60.66	61.53	59.80	2.56	1.89
P+Mj	L	593.98	546.54	551.75	541.43	548.04	550.71	542.77	30.80	22.73	78.56	76.79	77.66	76.21	77.35	78.11	76.60	2.48	1.83
	U	527.79	478.48	583.02	480.74	479.94	482.27	575.35	29.37	21.67	61.74	59.73	60.40	59.28	60.61	61.20	60.03	1.96	1.45
P+Rh+Mj	L	636.64	554.74	562.78	549.55	557.35	562.83	549.28	32.67	24.11	82.49	78.17	79.06	77.58	79.28	80.45	78.14	2.93	2.60
	U	575.29	492.84	504.76	492.76	489.54	494.33	482.48	28.36	30.93	66.14	61.82	62.82	61.06	62.13	63.04	61.23	2.93	2.16
L.S.D.																			
0.01	L	46.47	29.43	25.72	30.63	26.43	22.44	24.58			7.45	5.02	5.11	4.88	3.90	3.70	3.75		
	U	54.10	36.10	29.10	33.66	29.27	34.59	26.70			4.73	3.90	4.00	4.15	3.36	3.07	3.25		
0.05	L	34.07	21.58	18.86	22.46	19.38	16.45	18.02			5.46	3.68	3.75	3.58	2.86	2.71	2.75		
	U	29.67	26.45	21.38	24.68	21.46	25.36	19.58			3.47	2.86	2.93	3.04	2.46	2.25	2.38		

L = Lower surface, U = Upper surface

Each value is mean of five replicates.

tive exposed plants without any inoculation. In the exposed plants inoculated with Rhizobium alongwith M. javanica, the number of stomata were greater than their respective exposed plants without any inoculation except the number of stomata on both the leaf surfaces in post-inoculation exposures of plants. Instead, the number of stomata was less than respective exposed plants without any inoculation. The size of stomata and stomatal aperture in exposed plants inoculated with Rhizobium alongwith M. javanica was smaller than the respective exposed plant without any inoculation. But the size of stomatal aperture on lower leaf surface due to mixture of 0.2 ppm SO_2 and O_3 was greater than respective exposed plants without any inoculation. The number of stomata, size of stomata and stomatal aperture in exposed plants inoculated with Rhizobium together with root-knot nematodes were smaller than the exposed plants inoculated with Rhizobium. The number of stomata, size of stomata and stomatal aperture were highest in simultaneous inoculation exposure and lowest in post-inoculation exposure(Tables 46 and 47).

Trichomes of the leaves of lentil, like other experiments, responded to SO_2 and O_3 mixture by increasing their count and length. The number and length of trichomes in exposed plants inoculated with Rhizobium were greater than the unexposed plants and were smaller than the respective

Table 48. Interactive effects of mixtures of SO_2 and O_3, root-knot nematodes and root nodule bacteria on number of length of trichomes on leaves of lentil.

Treatment		Number of trichomes/cm²									Length of trichomes (μm)								
			0.1+0.1 ppm			0.2+0.2 ppm			L.S.D.			0.1+0.1 ppm			0.2+0.2 ppm			L.S.D.	
		C	Pe	S	Pt	Pe	S	Pt	0.01	0.05	C	Pe	S	Pt	Pe	S	Pt	0.01	0.05
P (Control)	L	2591.84	3097.25	2995.38	3097.62	3252.76	3253.82	3254.83	142.84	105.41	733.17	824.82	824.68	826.05	839.48	839.27	839.76	37.06	27.35
	U	1548.53	1889.21	1890.14	1890.76	1974.38	1974.92	1975.45	126.49	53.34	680.16	778.78	778.15	778.84	792.39	792.12	792.63	35.83	26.44
P+Rh	L	1963.52	2716.88	2717.27	2716.45	2957.05	2957.14	2958.27	167.52	123.62	591.26	743.08	743.46	744.14	780.91	780.34	781.55	28.38	20.94
	U	1082.87	1635.68	1634.82	1635.47	1778.72	1778.34	1779.27	103.79	76.59	507.58	695.34	695.30	696.76	730.31	730.20	730.84	28.96	21.37
P+Mi	L	2901.94	3252.11	3221.14	3283.08	3350.34	3317.81	3382.87	136.52	100.74	784.49	854.51	849.56	857.81	852.07	847.87	156.27	38.63	28.51
	U	1773.05	2002.56	1983.67	2021.45	2053.35	2033.61	2073.09	148.67	109.71	741.37	814.60	809.93	817.72	812.20	808.24	816.16	36.40	26.86
P+Rh+Mi	L	2545.63	3087.25	3038.81	3156.81	3160.70	3100.76	3221.78	126.77	93.55	694.23	813.82	801.48	820.09	815.38	803.67	823.34	32.96	24.32
	U	1453.42	1871.55	1836.73	1907.03	1928.03	1891.73	1965.02	99.53	73.45	633.65	754.26	743.06	764.22	769.86	662.49	777.30	42.74	31.54
P+Mj	L	2825.11	3190.17	3159.19	3221.14	3301.55	3285.29	3317.81	117.49	86.70	662.50	438.02	835.54	841.32	843.68	841.16	847.87	35.02	25.84
	U	1718.87	1964.77	1945.88	1983.67	2023.74	2013.86	2033.61	128.55	94.86	718.25	799.03	796.69	802.14	804.28	801.90	808.24	36.63	27.03
P+Rh+Mj	L	2242.15	2900.15	2906.71	2955.17	3056.99	3014.02	3100.76	150.00	110.69	630.17	783.19	766.55	793.69	795.52	786.13	807.50	29.08	21.46
	U	1282.74	1762.13	1729.67	1795.17	1865.19	1839.14	1891.73	110.74	81.72	552.56	733.05	724.27	742.73	755.19	745.95	766.10	32.74	24.16
L.S.D.																			
0.01	L	173.00	150.54	142.69	138.10	130.10	125.86	111.24			56.04	38.00	34.60	39.92	25.02	29.21	22.20		
	U	169.50	113.96	112.45	125.24	102.81	97.19	94.62			40.11	29.73	30.97	26.38	25.19	29.00	27.69		
0.05	L	126.84	110.38	104.62	101.26	95.38	92.28	81.56			41.09	27.86	25.35	29.27	18.36	21.42	16.28		
	U	124.27	83.56	84.45	91.83	75.38	71.26	69.38			29.41	21.80	22.71	19.34	18.47	21.26	20.30		

L = Loswer surface, U = Upper surface

Each value is mean of five replicates.

exposed plants without any inoculation. The number and length of trichomes in exposed plants inoculated with root-knot nematodes were greater than the unexposed plants as well as respective exposed plants without nematode. The number and length of trichomes in exposed plants inoculated with Rhizobium alongwith root-knot nematodes were greater than the unexposed plants. These parameters were, however, smaller than the exposed plants without any inoculation. The length and count of trichomes in exposed plants inoculated with Rhizobium alongwith either species of root-knot nematode were greater than the exposed plants inoculated with Rhizobium. The number and length of trichomes were highest in post-inoculation exposure and lowest in simultaneous inoculation exposure (Table 48).

DISCUSSION

Like ambient air pollution effects, in artificial exposures, SO_2 and O_3 individually and in mixture at both the concentrations suppressed seed germination of chickpea and lentil and induced greater post-emergence mortality of the seedlings. These effects were consistently concentration dependent. At 0.1 ppm, SO_2 and O_3 in mixture acted synergistically which resulted in greater inhibition of seed germination than the sum total of the inhibitions obtained with the pollutants acting individually at the

same concentration. But in inducing post-emergence mortality of the seedlings their interaction was antagonistic. At 0.2 ppm, their interaction for inhibition of seed germination was also antagonistic. Therefore, less inhibition of seed germination occurred when the pollutants, each at 0.2 ppm, were in mixture. In relation to their effects on post-emergence mortality of seedlings, interaction of the air pollutants in mixture (at 0.2 ppm) was also antagonistic. The results of the artificial exposure experiments confirm that SO_2, which was main constituent of the gaseous air pollutants in the ambient condition, alongwith other pollutants, caused inhibitory effects on seed germination. The suppression of enzymatic activities which are vital for seed germination are mainly regarded as mode of action of pollutants for adverse effect of pollution stress on seed germination (Horsman and Wellburn 1977; Soldatini and Ziegler, 1979; Wyss and Brunold, 1980; Pierre and Queiroz, 1982; Todd, 1958; Tanaka et al., 1982). Nandi et al. (1980) observed reduction in seed germination of Phaseolus vulgaris when exposed to SO_2, O_3 and SO_2 + O_3. Their study indicated that the reduction caused by exposures resulted from reduced activities of catalase and peroxidase and reduction in protein content of the seeds during germination. The inhibition was maximum due to SO_2-O_3 mixture. Boralker and Shindhe (1983) have also found inhibition

in seed germination of okra. Maximum inhibition occurred due to SO_2 + O_3 when compared with SO_2 and O_3 alone. As stated earlier (section II), the increase in post-emergence mortality of seedlings of both the crops may be the result of greater sensitivity of the seedlings to the air pollutants at the tender age.

In vitro growth of chick-pea and lentil strains of Rhizobium was also inhibited by the pollutants. SO_2 and O_3 in mixture at both the concentrations acted antagonistically. Consequently, growth of Rhizobium was better in plates exposed to the mixtures than to the individual pollutants at the same concentration. Chick-pea strain of Rhizobium was more sensitive to SO_2 and SO_2+O_3 than the lentil strain. Lentil strain of Rhizobium exhibited greater sensitivity to O_3. Chick-pea strain of Rhizobium is slow growing, non-acid producing and very sensitive even to slight acidity, while the lentil strain is fast growing, acid producing on culture media, and tolerant to slight acidic conditions (Vincent, 1977). This difference in their nature might have affected their responses. SO_2 which is converted into sulphuric acid after reacting with water might have lowered the pH of culture media. So, the chick-pea strain of Rhizobium exhibited poor growth because of its greater sensitivity to SO_2 and SO_2-O_3 mixture, while it was more tolerant to O_3.

SO_2 and O_3, singly and in mixture inhibited juvenile hatching of the M. incognita and M. javanica. The interactive effect of both the concentrations in inhibiting the juvenile hatching was synergistic. Juvenile hatching of the nematodes particularly of root-knot nematodes are influenced by various extraneous factors, including pH of the medium (Ahmad and Khan, 1964). The toxicity of the gases applied singly or in mixture might have resulted in inhibition of hatching of the juveniles from eggs. SO_2 by dissolving in water and lowering the pH, might have also caused the inhibition.

Plant growth and yield of chick-pea and lentil were considerably suppressed by SO_2 and O_3 individually and in mixture at both the concentrations. The toxicity of SO_2-O_3 mixtures of both the concentrations was consistently greater than the individual effects of SO_2 and O_3 of the same concentration. The response pattern of chick-pea and lentil to the exposures was more or less same. The effects of SO_2, O_3 and SO_2-O_3 mixtures observed on various plants have been reviewed by some workers (Reinert, 1984; Olszyk and Thompson, 1985; and Heck et al. 1986; Miller, 1987). In various experimental studies the relative toxicity of SO_2 and O_3 have been compared and O_3 have been found more toxic than SO_2 (Reinert, 1984). In the present study both SO_2 and O_3 at the concentrations used were toxic to chick-pea and lentil and appreciable reductions were recorded out; O_3 was more toxic than SO_2 at both the concentrations. In exposed plants inoculated with Rhizobium

reductions were comparatively less in all the parameters of growth and yield, leaf pigment and seed protein contents than exposed plants without Rhizobium inoculation. This observation is significant and emphasize the importance of Rhizobium in relation to air pollution damage to legumes, in addition to its well established role in symbiotic nitrogen fixation. SO_2 and O_3 interacted antagonistically in causing reductions in plant growth. The reductions, in general, caused by the mixture of SO_2-O_3 was less than sum of the reductions from SO_2 and O_3 exposures singly.

In exposed plants, irrespective of the inoculation of the nematodes and/or Rhizobium, chlorophyll contents in leaves of both chick-pea and lentil were reduced in comparison to unexposed plants. This effect was similar to the results obtained in ambient air pollution effect studies (Section.II). As discussed in the section II, sulphite which results from conversion of SO_2 after entry into the plants cause destruction of chlorophyll (Thomas et al., 1943; Barrett and Benedict,1970; Pandey and Rao, 1978; Lauenroth and Dodd, 1981), or phaeophytinization of chlorophyll and renders it photosynthetically inactive (Rao and LeBlance, 1966). Metabolic processes and enzymatic activities of plant were decreased at the higher toxic concentrations of SO_2 (Todd, 1958; Horsman and Wellburn,

1977; Soldatını and Zıegler, 1979; Wyss and Brunold, 1980; Pıerre and Queıroz, 1982; Tanaka et al., 1982). Reduced chlorophyll of the leaves and lowered enzymatıc actıvıtıes ın the exposed plants would cause reduced carbohydrate productıon by the plants, whıch ın turn result ın poor growth and declıned health of the plants. Both SO_2 and O_3 exhıbıted anatogınıstıc ınteractıve effects on the chlorophyll contents of leaves of both chıck-pea and lentıl. O_3 accumulates ın the palısade layer of the leaves and causes theır bleachıng or dıscolouratıon through destructıon of chlorophyll. The affected cells ultımately collapse (Macdowall, 1965; Sakakı et al., 1983). The observatıon of Rhoads and Brennan (1978) that O_3 ınhıbıted the chloroplast electron transport system ın a sensıtıve tobacco cv. Bel W_3 and the ınhıbıtıon was smaller ın a resıstant cultıvar Bel-B, whıle ın vıtro the ısolated chloroplasts from both the cultıvars reacted sımılarly suggest that the structure or physıology of cell membrane affect the movement of O_3, whıch ıs the ınıtıal sıte of actıon for O_3 and causes the leakage of potassıum and some electrolytes (Rhoads and Brennan, 1978; Heath and Frederıck, 1979; Heck et al., 1986). The reductıon ın the chlorophyll, whıch ıs responsıble for the reductıon ın photosynthesıs ın plants and other affected metabolıc processes ultımately exhıbıted theır ımpact on plant growth.

The reduction in yield characters of the plants was directly correlated with the reduced plant growth. The decrease in assimilates might be the reason of less flower bud formation (Whitemore and Mansfield, 1983), premature fall of flowers (Gupta and Ghouse 1978a) and failure of fertilization because of the retarded growth of pollen tubes by SO_2 (Linzon, 1978). These effects jointly contributed towards poor flowering and fruiting of the plants. O_3 has been shown responsible for shedding of pollen grains, reducing the germination and growth of pollen grains and inactivation of ovules (Kress et al., 1986). Protein contents of chick-pea and lentil seeds were reduced by the exposures of the plants in all treatments in comparison to unexposed plants. SO_2+O_3 exhibited antagonistic interaction in their effect on protein content of seeds. Direct interference of the air pollutants in the metabolic activities of plants related to protein synthesis and/or indirect effects by causing poor plant growth (Khan and Malhotra, 1983; Cracker, 1972; Cracker and Starback, 1972), and inhibiting root nodulation in Rhizobium inoculated plants, possibly reduced the seed proteins. The reduction of protein contents in exposed plants inoculated with Rhizobium was relatively less than exposed plants without Rhizobium and reduction was directly correlated with the reduction in

the root nodulation.

The response pattern of the leaf epidermal characters to SO_2 and O_3 and their mixture in artificial exposures was similar to those present in ambient air pollution effects (Section II). In most of the earlier studies (Jacobson and Colavito, 1976; Kondo and Sugahara, 1978; Rosen et al., 1978; Elkiey and Ormrod, 1979 and Olszyk and Tibbitts, 1981a, 1981b) stomata has been found to be adversely affected by SO_2 and O_3 alone and in combination and was correlated with the extent of leaf injury size. In the present studies, stomatal count and aperture size were reduced by the exposures. Since stomata are the passage for entry of SO_2 and O_3, it seemed that as a resistance mechanism for preventing the entry of pollutants, plants responded by reducing the number and size and aperture size of stomata and thus minimized their entry. Similar observations have been made by Ghouse and Khan (1978), Zaidi et al., (1979), Sharma et al., (1980) and Gupta and Ghouse (1978a, 1978b). SO_2 and O_3 induced stomatal closures have also been reported in various crop plants which regulates the entry of the air pollutant(s) (Elkiey and Ormrod, 1979; Kondo and Sugahara, 1978; Rosen et al., 1978; Olszyk and Tibbitts, 1981a, 1981b). O_3 is also well known to alter the permeability of cell membranes to water (Heath, 1975). The reduction in number of stomata, size of stomata and

stomtal aperture might be also due to the poor and stunted growth of exposed plants because of reduced water absorption through the suppressed and poorely developed roots in order to check water loss from leaf surfaces. Trichome - hydathodes in case of chick-pea, through which water containing various minerals and organic compounds exudate were possibly reduced as the structural adaptation in response to diminished water pressure in plants. Exposures increased the trichomes number and length on leaf surfaces of both the crops. Trichomes on plant surfaces provide protection and regulate the temperature of plants and prevent water loss through transpiration. Similar responses of trichomes on leaf surface of Psidium guajava, Croton bonplandianus, Euphorbia hirta and Abelmoschus esculentus were recorded by Ghouse and Khan (1978), Zaidi et al., (1979, Gupta and Ghouse (1978a, 1978b). The interactive effects of SO_2 and O_3 on the various leaf epidermal characters were antagonistic.

Exposure of plants of chick-pea and lentil, inoculated with M. javanica or M. incognita alone or together with Rhizobium, to SO_2 or O_3 and their mixtures suppressed the root-knot disease. Root galls and eggmasses were reduced on the roots of exposed plants. Higher concentrations were invariably more inhibitory than the lower concentrations. SO_2 and O_3 together exhibited antagonistic effects on the root galling and eggmass production. The reductions caused

by the mixtures of the air pollutants were less than sum of the reductions caused by SO_2 and O_3 individually at the same concentration. The inhibitory effect of the exposures might have resulted from direct toxic effect on nematodes or indirectly through the changed physiology and altered nutritional status of the host plants. In a study, Weber et al., (1979) found different responses of some nematodes infecting soybean exposed to SO_2 and O_3 alone and in combination. Reproduction and development of Heterodera glycines and Paratrichodorus minor were inhibited but Belonolaimus longicaudatus was not affected. SO_2 enhanced reproduction of Pratylenchus penetrans. Foliar injury of begonia induced by exposures to O_3 or SO_2-O_3 mixture inhibited Aphelenchoides fragariae. Bisessar and Palmer (1984) found 20% increase in root galling on tobacco by M. hapla when plants were exposed to ambient O_3, exhibiting syngergistic interaction between the nematode and the pollutant.

Simultaneous inoculation exposures of the plants to SO_2, O_3 and SO_2-O_3 mixture was most effective in suppressing root galling and eggmass production, while in the post-inoculation exposures of plants was least affective.Weber et al., (1979) obtained greater inhibition in reproduction of A. fragariae on begonia leaves when exposed to SO_2, O_3 and SO_2-O_3 mixture prior than nematode inoculation than the plants exposed to pollutant after nematode inoculation.

In the present investigations, the adverse effects of root-knot nematodes on various parameters were highest in post-inoculation of plants and least in simultaneous inoculation exposures. The adverse effect of the nematodes were greater in post-inoculation exposures of plants than the pre-inoculation exposures. This variation in the adverse effect of root-knot nematodes on the parameters of the plants might be due to the variation in the development of galls due to exposure initiation in relation of nematode inoculation. The minimum number of galls in the simultaneous inoculation exposure of pollutants gives an evidence of direct effect of pollutants on the nematodes (juveniles) making them incapable to penetrate the root, while in post-inoculation exposure where no pollution stress occurred at the time of their penetration, highest number of root galls developed. But still, relatively root-glling was less when compared with control which is also suggestive of indirect effect of air pollutants on the nematodes. In the pre-inoculation exposure also the indirect effect of air pollutants can be envisaged because the exposed plants before inoculation of the nematodes had already altered physiological status. Air pollutants usually cause visible or invisible injuries to the plants through the metabolic changes i.e. the formation of phenolic substances (Howell and Kremer, 1973) and reduction in carbohydrates

and minerals i.e potassium (Mass et al., 1973; Tingey, 1974). This altered physiological status of the exposed plants might have inhibited the gall formation (Weber et al., 1979) and eggmass production (Oteifa, 1953). Additionally, the increased soil acidity through SO_2 dissolution in soil water might have also affected the root-knot nematodes.

Root nodulation on chick-pea and lentil was suppressed by SO_2 and O_3 alone and in combination. Like root-knot nematodes SO_2 and O_3 showed antagonistic interaction on root nodulation as well. Records of suppression of root nodulation by SO_2, O_3 and SO_2-O_3 mixture are available in literature (Reinert et al., 1971; Tingey and Blum, 1973; Reinert and Weber, 1980; Klarer et al., 1984; Kumar, 1986). The reduction in the nodule number may be either by the direct inhibitory effect of pollutants on the root-nodule bacteria, Rhizobium present in soil in free living stage or indirectly through the host plant due to presence of inhibitors or by reduced translocation of growth substances to the root (Tingey, 1974) or because of poor plant growth with less extensive root system.

Root nodule bacteria favour leguminous plants. Even in the presence of air pollutants when the root nodulation was considerabley suppressed, some favourable effects

of the bacteria were exhibited on the plant parameters. Root-knot nematodes interacted with Rhizobium antagonistically and inhibited each other. This aspect has been discussed in detail in the Section II. The presence of maximum nodules in the simultaneous inoculation exposure might be due to the lowest galling by root-knot nematodes and for the same reason lowest number of nodules were observed in the post-inoculation exposure because of highest root galling.

Both SO_2 and O_3 alone and in combination interacted antagonistically with M. incognita, M. javanica and Rhizobium ultimately causing less reduction or increase on the various parameters. In this respect, the interaction of SO_2 and O_3 in mixture was antagonistic.

The findings show that air pollutant exposures affected all the living components of the system. The order of toxicity of considered pollutants was $SO_2+O_3 > O_3 > SO_2$. In this respect SO_2 and O_3 at both the concentrations (0.1 and 0.2 ppm) in general on plant growth and yield etc. showed antagonistic interaction. The pollutants were also toxic to Rhizobium and root-knot nematodes, M. incognita and M. javanica.

SUMMARY

Inhibition of seed germination of chick-pea and lentil occurred by exposures of pots to two different concentrations of SO_2 and O_3 (0.1 and 0.2 ppm) singly and in mixture. The exposures also caused post-emergence mortality of the seedlings. The effect of 0.2 ppm SO_2 and O_3, singly and in mixture (0.2 + 0.2 ppm) was invariably greater than 0.1 ppm SO_2 and O_3 singly and in mixture. O_3 was more inhibitory than SO_2 at both the concentrations. Similarly mixture of SO_2 and O_3 at each concentration was more suppressive than SO_2 or O_3 singly at their respective concentrations. The chick-pea was more sensitive than lentil to the exposures at germination stage. 0.1 ppm of SO_2 did not cause inhibition of seed germination of lentil. But after emergence the seedlings of lentil exhibited more sensitivity than chick-pea.

SO_2 and O_3 alone and in combination also suppressed the *in vitro* growth of chick-pea and lentil strains of *Rhizobium*. Both the pollutants singly and in mixture were more inhibitory at the higher the concentrations. The chick-pea strain of *Rhizobium* showed greater sensitivity to the exposures of SO_2 than lentil strain. But to O_3, lentil strain of *Rhizobium* was more sensitive. The mixture of SO_2 and O_3 at both the concentrations cuased greater reductions

in the growth of chick-pea strain than lentil strain. The mixtures of SO_2 and O_3 at both the concentrations were more toxic than the individual pollutants at their respective concentrations.

Juvenile hatching of M. incognita and M. javanica was suppressed by the exposures. The higher concentration of the pollutants were more suppressive than their lower concentrations. O_3 was more suppressive than SO_2. The effect of the mixture of the pollutants was greater than their individual effects. M. incognita was apparently more sensitive than M. javanica in this respect.

SO_2 (0.1 and 0.2 ppm) and O_3 (0.1 and 0.2 ppm) alone and in mixture (0.1 SO_2 + 0.1 O_3, 0.2 SO_2 + 0.2 O_3) caused reductions in plant growth (length, fresh and dry weights of shoot and root), yield (flowering and fruiting), leaf pigments and seed proteins of chick-pea and lentil in artificial exposures. The higher concentration of both the pollutants and their mixture was consistently more harmful for all the considered parameters of plant growth, yield, leaf pigments and seed proteins. The suppressive effect of the pollutants varied. O_3 was apprarently more toxic than SO_2 and SO_2-O_3 mixtures were more toxic than the individual pollutants at the same concentration. The favourable effects of Rhizobium noticed in unexposed plants

in terms of increase in plant growth, yield etc. was suppressed by the exposures. But still, plant growth and yield of Rhizobium inoculated exposed plants were better than exposed plants without Rhizobium. M. incognita and M. javanica caused reductions in plant growth and yield. In the presence of Rhizobium, the reductions caused by either species of Meloidogyne were less because of antogonistic interaction between Meloidogyne species and Rhizobium. In the exposed plants inoculated with M. incognita or M. javanica, plant growth, yield etc. were smaller than the nematode infected unexposed plants or the exposed plants without the nematode. Plant growth, yield, leaf pigments and seed proteins in exposed plants inoculated with either species of Meloidogyne and Rhizobium were less than the unexposed plants inoculated with root-knot nematode and Rhizobium or than the exposed plants inoculated with Rhizobium, but were greater than the exposed plants without any inocualtion and the exposed plants inoculated with either species of Meloidogyne. These parameters were invariably greatest in simultaneous inoculation exposures and lowest in post-inoculation exposures of plants to the air pollutants singly or in mixtures in both chick-pea and lentil.

Exposures of chick-pea and lentil plants to the air pollutants inhibited root galling and eggmass production

of M. incognita and M. javanica. The higher concentration was invariably more inhibitory, irrespective of the air pollutants involved or their mixture. Rhizobium also suppressed the root galling and eggmass production of both the species of Meloidogyne. The number of galls and eggmasses in exposed plants inoculated with Rhizobium and either species of Meloidogyne was less than unexposed plants inoculated with both the organisms or than the exposed plants inoculated with root-knot nematode alone. Root galling and eggmass production were greatest in post-inoculation exposures and lowest in simultaneous inoculation exposures. The degree of suppression varied according to the pollutant used singly or in mixture and their concentration. O_3 was more toxic than SO_2 and mixtures of the pollutants were more toxic than individual pollutants. The exposures also suppressed root nodulation on chick-pea and lentil; the higher concentration singly or in mixture being more inhibitory. M. incognita and M. javanica also suppressed root nodulation and infected some nodules. The number of total and functional nodules in exposed plants inoculated with Rhizobium and either species of Meloidogyne were smaller than unexposed plants inoculated with Rhizobium and M. incognita/M. javanica or than exposed plants inoculated with Rhizobium alone. The number of infected nodules was also reduced in exposed plants. The number of total and functional nodules were highest in simultaneous inoculation exposures

and lowest in post-inoculation exposures. The number of infected nodules were highest in pre-inoculation exposures and lowest in simultaneous inoculation exposures of plants.

The leaf epidermal characters of chick-pea and lentil were also influenced by the exposures. The number of stomata, size of stomata and stomatal aperture and number and length of trichome-hydathodes were reduced by the pollutants. The number and length of trichomes, however, increased. The higher concentration of the pollutants alone or in combination was more effective than their low concentrations. The increasing effect of Rhizobium on the measures of stomata and trichome-hydathodes were influenced by the exposures. The exposures also influenced the adverse effect of M. incognita and M. javanica on these epidermal characters. These parameters in exposed plants inoculated with both Rhizobium and M. incognita/M. javanica were also influenced by the air pollutants. These parameters were greatest in simultaneous inoculation exposures and lowest in post-inoculation exposures of plants.

Air pollutants also suppressed the individual and combined effects of Rhizobium and either species of Meloidogyne on the number and length of trichomes. The number and length of trichomes were greatest in post-inoculation exposures and lowest in simultaneous inoculation exposures of plants.

SECTION IV

INTERACTION OF SIMULATED ACID RAIN, ROOT-KNOT NEMATODES AND ROOT NODULE BACTERIA ON CHICK-PEA AND LENTIL

SO_2 and NO_x constitute major portion of gaseous air pollutants produced through combustion of fossil fuels. They form dilute concentrations of sulphuric and nitric acids in the atmosphere which fall on earth as acid precipitation. This acid precipitation brings about several changes in terrestrial and aquatic ecosystems. Their adverse effects on forest trees and some crops have been recognized. Some studies also show their adverse effects on microorganisms associated with the plants and alteration of host-oparasite relationships. The effect of acid precipitation on root nodulation and root-knot nematodes has gained very little study. In the present study, interaction of simulated acid rain, root-knot nematodes and root nodule bacteria on chick-pea and lentil, their interactive effects on the various parameters of the crops and on root nodule bacteria and root-knot nematodes have been examined. In addition to it, effects of various pH levels on seed germination of both the crops, juvenile hatching of the root-knot nematodes and growth of Rhizobium in vitro have been investigated.

MATERIALS AND METHODS

Seed germination

For this study, five pH levels viz., 6, 5, 4, 3.2, and 2.5 were chosen. Seeds of chick-pea (cv. T-3) and lentil (cv. T-36) (100 seeds/pot) were sown in 2 separate series of clay pots (30 cm) filled with sterilized sand. The pots were completely moistened with water of pH 6, 5, 4, 3.2 and 2.5. The acidified water of different pH was obtained by adding 1N H_2SO_4 in distilled water. In control pots only distilled water was added. Each treatment was replicated five times. The pots were kept in glasshouse. After seven days of sowing, seed germination and post-emergence mortality of seedlings were determined for each treatment as done in section II.

Growth of Rhizobium

The effect of the pH levels on growth of chick-pea and lentil strains of Rhizobium was studied separately by using YMA medium. The pH of the YMA medium was adjusted at different levels viz., 6, 5, 4, 3.2, 2.5 by adding 1N H_2SO_4. The pH level was adjusted and determined by pH meter before autoclaving the medium. The media with different pH levels, were poured in sterilized 10 cm petriplates (25 ml). For control, the pH of medium was maintained at 7.

The one series of petriplates (5 plates for each pH level) were inoculated with diluted culture of chick-pea strain of Rhizobium and other series with lentil strain. All inoculations were done in aseptic conditions on a laminar flow bench. The petriplates were then incubated at 28°C(±2)in an incubator. After 10 days of incubation, radius of the colony was measured as done in the section III.

Juvenile hatching

The effect of different pH levels on juvenile hatching of M. incognita and M. javanica was examined by keeping 50 eggmasses of approximately equal size in 6 cm petriplates added with 15 ml of water of different pH levels viz., 6, 5, 4, 3.2 and 2.5. For control, the eggmasses were kept in petriplates containing 15 ml of sterilized distilled water. Each treatment was replicated five times. The petriplates were incubated at 28°C(±2) in an incubator. After seven days of incubation, the hatched juveniles were counted and by determining the number of hatched juveniles per eggmass, per cent reduction over control was calculated.

Interaction studies

To study the interaction of simulated acid rain, root nodule bacteria and root-knot nematodes and their interactive effects on chick-pea cv. T-3 and lentil cv. T-36, the plant culture was done as described in the

section II.

Inoculation of Rhizobium was done at the time of sowing by bacterization of the seeds as stated in the section II,while the inoculation of Meloidogyne incognita and M. javanica was done 1 month after sowing. The inoculum level of the nematodes was invariably 1000 juveniles (J_2) per pot. For chick-pea, six sets of pots with following inoculations for each pH level (5 and 3.2) were obtained before acid rain treatment.

T1 = Crop plant (control)

T2 = Crop plant + Rhizobium

T3 = Crop plant + Meloidogyne incognita

T4 = Crop plant + Rhizobium + M. incognita

T5 = Crop plant + M. javanica

T6 = Crop plant + Rhizobium + M. javanica

For the study two pH levels viz., 5 and 3.2 were selected and acidified water was prepared by mixing 1N H_2SO_4 in sterilized distilled water. For acid rain treatment of the plants, acidified water was sprayed over the plants designated to receive the treatment with the help of showers in closed chambers in glasshouse. In one time exposure, 7 mm acid rain treatment was given and repeated twice a week till the termination of the experiment since the beginning of acid rain treatment.

Treatments of plants with acid rain (both pH 5 and 3.2) were started at three different times in relation to nematode (J_2) inoculation as given below.

(i) Pre-inoculation treatment

The acid rain treatment started one week before nematode inoculation.

(ii) Simultaneous inoculation treatment

Acid rain treatment started at the time of nematode inoculation.

(iii) Post-inoculation treatment

Acid rain treatment started one week after nematode inoculation.

One set of pots was kept in glasshouse to serve as control for respective treatments and inoculations. After 100 days of seed sowing, the experiment was terminated and the various parameters as considered and described in the section II were studied.

A similar experiment was conducted using lentil (cv. T-36) as test plants. All the treatments and inoculations and considered parameters at the termination of the experiment were same as for chick-pea.

RESULTS

Seed germination

The soil acidity suppressed seed germination of both chick-pea and lentil. Seed germination showed stepwise decrease with the increasing acidity. At pH 6, the reduction in seed germination was 2.20 and 1.14% in chick-pea and lentil respectively. But at pH 2.5, the reduction was considerably high. It was 39.56 and 36.36%, in chick-pea and lentil respectively. The reduction in seed germination was greater in chick-pea than lentil. Post-emergence mortality of seedlings of both the crops was also influenced. The mortality of the seedlings increased with the increasing

Table 1. Effect of pH on seed germination of chick-pea and lentil and post-emergence mortality of the seedlings.

pH	Chick-pea			Lentil		
	Germination %	Reduction over control %	Seedling mortality %	Germination %	Reduction over control %	Seedling mortality %
Control	91		0	88		3
6.0	89	2.20	1	87	1.14	3
5.0	77	15.38	4	77	12.50	5
4.0	70	23.08	8	71	19.32	9
3.2	63	30.77	12	62	29.55	15
2.5	55	39.56	15	56	36.36	16

acidity. At pH 6, the mortality of seedlings was 1 and

3% in chick-pea and lentil respectively. But at pH 2.5, it increased to 15 and 16%. The post-emergence mortality of the seedlings was greater in lentil than chick-pea (Table 1).

Growth of Rhizobium

Growth of chick-pea and lentil strains of Rhizobium was affected by the pH level of the medium. At pH 6, the growth of chick-pea strain was unaffected while the growth of lentil strain of Rhizobium showed slight increase. At pH 5, growth of both the strains decreased. The reduction in colony growth of chick-pea and lentil strains was 20.27%

Table 2. Effect of pH on growth of chick-pea and lentil strains of Rhizobium in culture medium.

pH	Chick-pea		Lentil	
	Colony growth (radial) mm	Reduction over control %	Colony growth (radial) mm	Reduction over control %
Control	7.4		13.6	
6.0	7.4	0.00	14.0	
5.0	5.9	20.27	11.7	13.97
4.0	3.6	51.35	8.8	35.29
3.2	-	-	3.1	77.21
2.5	-	-	-	-

and 13.97% respectively. At pH 4, further reduction in

growth occurred. The reduction was 51.35% in chick-pea strain and 35.29% in lentil strain. At pH 3.2, growth of chick-pea strain was completely inhibited, while 77.21% reduction occurred in growth of the lentil strain. At pH 2.5, growth of the lentil strain was also completely inhibited (Table 2).

Juvenile hatching

The acidity of the water suppressed juvenile hatching of the root-knot nematodes, M. incognita and M. javanica. The hatching was progressively suppressed by the increasing

Table 3. Effect of different pH levels on juvenile hatching of Meloidogyne incognita and M. javanica

pH	M. incognita		M. javanica	
	Juveniles/ eggmass	Reduction over control %	Juveniles/ eggmass	Reduction over control %
Control	364		341	
6.0	280	23.08	269	21.11
5.0	173	52.47	162	52.49
4.0	110	69.78	96	71.85
3.2	83	77.20	74	78.30
2.5	46	87.36	37	89.15

acidity. At pH 6, the reduction was 23.08 and 21.11% in M. incognita and M. javanica, respectively. At pH 2.5,

per cent reduction was 87.36 and 89.15 in M. incognita and M. javanica respectively (Table 3).

CHICK-PEA, Cicer arietinum L.

Plant growth and yield

Simulated acid rain of pH 5 and 3.2 adversely affected plant growth (length, fresh and dry weights of shoot and root) and the yield characters (number of flower and fruits) of chick-pea. The effects of acid rain of pH 3.2 were significantly greater than pH 5. Acid rain of pH 3.2 caused significant reductions (at P = 0.01) in all the growth and yield parameters. Acid rain of pH 5 reduced length and fresh weight of shoot and number of flowers and fruits (significant at P = 0.01), and length and fresh weight of root and dry weights of shoot and root (significant at P = 0.05). The favourable effects of Rhizobium inoculation on the growth and yield parameters were suppressed in the plants treated with acidified rains. The extent of suppression was related to pH of the simulated acid rain; being greater with acid rain of pH 3.2 (Tables 4 and 5, Figs. 1A and 1B).

Root-knot nematodes, M. incognita and M. javanica affected growth and yield parameters of chick-pea differently. M. incognita caused significant reductions in all growth and yield parameters. The reduction in shoot dry

Table 4 . Interactive effects of simulated acid rain, root-knot nematodes and root nodule bacteria on plant length and fresh weight of chick-pea.

Treatment		Length (cm)								Fresh weight (g)								
		pH 5			pH 3.2			L.S.D.		pH 5				pH 3.2			L.S.D.	
		C	Pe	S	Pt	Pe	S	Pt	0.01	0.05	C	Pe	S	Pt	Pe	S	Pt	0.01	0.05
P (Control)	S	32.6	30.1	30.1	30.2	21.7	21.5	21.7	2.56	1.89	25.25	22.95	22.90	22.95	15.30	15.25	15.30	2.33	1.72
	R	22.7	20.8	20.8	20.9	17.6	17.5	17.6	1.88	1.39	17.50	16.20	16.20	16.20	11.20	11.25	11.20	1.63	1.20
P+Rh	S	42.4	38.2	38.2	38.4	24.5	24.5	24.5	3.08	2.27	38.55	33.35	33.35	33.40	18.65	18.65	18.70	2.87	2.12
	R	27.5	25.1	25.0	25.1	19.5	19.4	19.6	2.28	1.68	24.25	21.55	21.55	21.60	12.60	12.60	12.65	1.83	1.35
P+Mi	S	25.2	23.9	23.7	23.5	19.0	18.6	18.4	1.98	1.46	21.85	20.40	20.30	20.05	14.70	14.55	14.45	2.09	1.54
	R	16.41	16.2	16.1	15.8	15.3	15.0	14.8	1.53	1.13	14.80	13.85	13.75	13.60	10.70	10.65	10.50	1.46	1.08
P+Rh+Mi	S	30.7	28.2	27.7	27.5	20.5	19.9	19.5	2.49	1.84	30.40	26.90	26.45	25.75	16.50	16.15	15.90	3.24	2.39
	R	19.6	18.7	18.3	18.0	16.4	15.9	15.5	1.63	1.20	18.30	16.90	16.50	16.17	11.65	11.40	11.25	1.86	1.37
P+Mj	S	29.3	28.7	28.5	28.4	21.2	21.1	21.1	2.55	1.88	24.15	22.30	22.20	22.05	15.15	15.05	15.00	2.48	1.83
	R	19.8	18.9	18.7	18.6	16.9	16.8	16.6	1.59	1.17	16.75	15.05	15.65	15.50	10.95	10.90	10.85	1.75	1.29
P+Rh+Mj	S	36.4	34.9	34.2	33.8	23.6	23.3	22.9	2.93	2.16	34.15	31.05	30.60	30.05	17.90	16.65	17.40	2.78	2.05
	R	23.9	22.3	21.9	21.6	18.5	18.1	17.8	1.60	1.18	21.85	20.05	18.70	19.45	12.25	12.05	11.85	2.10	1.55
L.S.D.																			
0.01	S	3.72	3.66	3.71	3.59	2.96	3.04	2.97			2.03	2.29	2.06	1.95	1.70	1.65	1.62		
	R	1.73	1.69	1.64	1.72	1.65	1.62	1.58			1.55	1.64	1.61	1.70	1.46	1.51	1.49		
0.05	S	2.73	2.68	2.72	2.63	2.17	2.23	2.18			1.49	1.68	1.51	1.43	1.25	1.21	1.19		
	R	1.27	1.24	1.20	1.26	1.21	1.19	1.16			1.14	1.20	1.18	1.25	1.07	1.11	1.09		

C = Control, Pe = Pre-inoculation, S = Similtaneous inoculation, Pt = Post-inoculation, P = Plant, Rh = Rhizobium, Mi = Meloidogyne incognita, Mj = M. javanica, (These abbreviations are common to all subsequent tables in this section)

S = Shoot, R = Root

Table 5. Interactive effects of simulated acid rain, root-knot nematodes and root nodule bacteria on dry weight, flowering and fruiting of chick-pea.

Treatment		Dry weight (g)								Flower/Fruit								
		pH 5			pH 3.2			L.S.D.			pH 5			pH 3.2			L.S.D.	
		C	Pe	S	Pt	Pe	S	Pt	0.01	0.05	C	Pe	S	Pt	Pe	S	Pt	0.01	0.05
P (Control)	S	5.80	5.45	5.45	5.45	3.60	3.55	3.60	0.46	0.34	FL 96.8	84.8	84.6	84.8	42.6	42.4	42.6	4.92	3.63
	R	4.15	3.95	3.90	3.95	2.80	2.80	2.85	0.24	0.18	FR 64.6	42.6	42.4	42.8	24.6	24.4	24.4	7.16	5.28
P+Rh	S	8.95	7.90	7.95	7.95	4.45	4.45	4.45	0.80	0.59	FL 150.4	127.4	127.0	127.2	55.4	55.4	55.6	7.83	5.78
	R	5.75	5.30	5.30	5.35	3.25	3.20	3.25	0.37	0.27	FR 110.2	58.2	58.2	58.4	29.2	29.0	29.2	7.85	5.79
P+Mi	S	5.10	4.85	4.80	4.75	3.45	3.40	3.30	0.47	0.35	FL 58.8	54.4	53.8	53.2	38.8	38.2	37.4	4.28	3.16
	R	3.45	3.40	3.35	3.30	2.70	2.70	2.65	0.26	0.19	FR 35.8	25.2	24.6	24.2	22.8	22.6	22.4	4.91	3.62
P+Rh+Mi	S	7.20	6.45	6.30	6.10	3.95	3.85	3.70	0.56	0.41	FL 70.2	64.2	62.8	61.6	45.8	44.2	42.6	5.11	3.77
	R	4.00	4.15	4.05	3.95	2.95	2.90	2.80	0.27	0.20	FR 45.4	21.6	21.4	21.6	25.6	24.8	24.4	5.30	3.91
P+Mj	S	5.45	5.30	5.25	5.20	3.55	3.55	3.50	0.62	0.46	FL 70.4	62.2	64.4	63.4	40.2	39.8	39.4	4.74	3.50
	R	3.85	3.80	3.80	3.75	2.75	2.75	2.70	0.18	0.13	FR 48.0	34.4	35.8	33.2	23.6	23.4	23.2	5.23	3.86
P+Rh+Mj	S	8.15	7.40	7.30	7.15	4.25	4.20	4.10	0.84	0.62	FL 98.2	89.8	87.4	84.8	50.2	49.4	48.6	6.34	4.68
	R	4.90	4.95	4.85	4.80	3.15	3.10	3.00	0.28	0.21	FR 67.2	45.8	44.4	43.0	27.6	27.2	26.6	6.21	4.58
L.S.D.																			
0.01	S	0.94	0.85	0.93	0.98	0.42	0.35	0.38			FL 6.30	5.93	6.12	5.97	4.30	4.38	4.49		
	R	0.63	0.56	0.52	0.59	0.42	0.41	0.37			FR 5.40	4.31	4.38	4.23	3.30	3.45	3.36		
0.05	S	0.69	0.62	0.68	0.72	0.31	0.26	0.28			FL 4.62	4.35	4.49	4.38	4.15	4.21	3.29		
	R	0.46	0.41	0.38	0.43	0.31	0.30	0.27			FR 3.96	3.16	3.21	3.10	2.42	2.53	2.46		

S = Shoot, R = Root

FL = Flower, FR = Fruit

Each value is mean of five replicates.

weight was however, significant only at P =0.05. M. javanica caused less reductions in comparison to M. incognita. The reductions in root length and yield parameters were significant at P = 0.01 and shoot length at P = 0.05, while the reductions in fresh and dry weights of shoot and root were not significant. When plants were treated with acid rain and inoculated with the nematodes, the growth parameters were lowest. Acid rain of pH 3.2 was more effective than pH 5 in this respect (Table 4 and 5, Figs. 1A and 1B).

Among the three timings of dispensing of the acid rains, highest plant growth was observed in pre-inoculation treatment. But the differences among the timings of acid rain dispensings were not significant. M. incognita in the presence of Rhizobium also significantly (P = 0.01) reduced the root length, fresh and dry weights of shoot and yield parameters. Fresh weight of root was reduced significantly at P = 0.05, while reduction in length of shoot and dry weight of root was not significant. M.javanica in presence of Rhizobium did not cause reductions in plant growth. Instead significant (at P = 0.01) increase in length of shoot, fresh and dry weights of shoot and root was recorded. Reduction due to combined effect of M. incognita and Rhizobium and increase due to M. javanica and Rhizobium combination were suppressed by the acidified rains. The adverse effect of pH 3.2 was greater than pH 5. The plant growth and yield was highest in the pre-inoculation treatment of acid rains and was lowest in the post-inoculation treatment (Tables 4 and

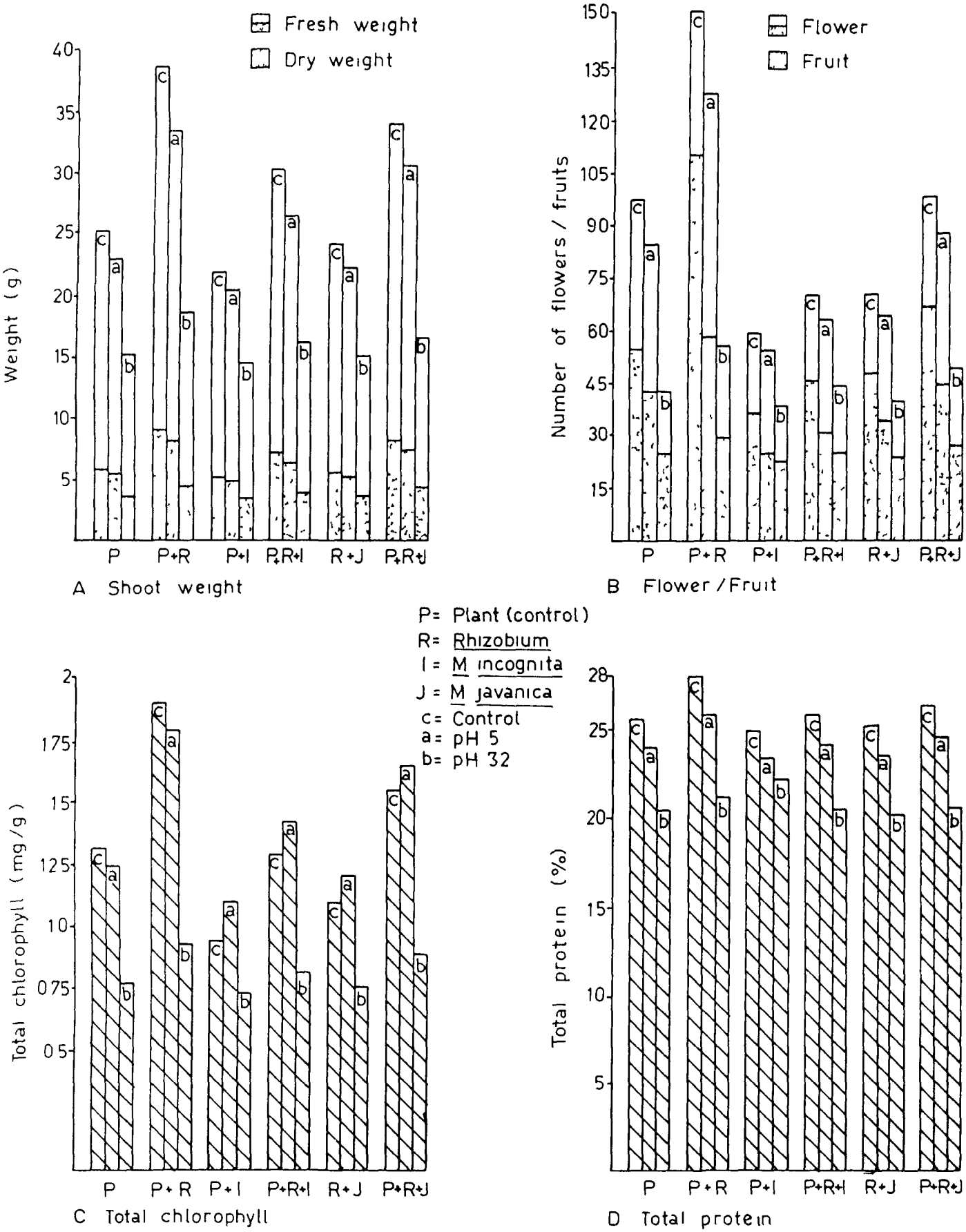

Fig 1 Interactive effects of simulated acid rain, root-knot nematodes and root nodule bacteria on some parameters of chick-pea in simultaneous inoculation treatment

5, Figs. 1A and 1B).

Root-knot disease and root nodulation

Root galling and eggmass production were suppressed by acid rains; reductions being greater with acid rain of pH 3.2. The reduction in root galling and eggmass production of both the nematodes by acid rains occurred even in the presence of Rhizobium. The acid rain in all the three timings of applications, viz., pre-, post- and simultaneous inoculation, suppressed the root-knot nematodes, with or without Rhizobium, which was highest in pre-inoculation and was lowest in post-inoculation (Table 6).

The acid rain of pH 3.2 and 5 also inhibited root nodulation. Root nodulation was greatest in pre-inoculation treatment of the acid rains and lowest in post-inoculation treatment. In the nematode inoculated plants, the number of both total and functional nodules was highest in pre-inoculation treatment and lowest in post-inoculation treatment. The suppression observed in the root nodulation by the root-knot nematodes was adversely affected by the acid rain treatments. The number of nodules infected with nematodes was also significantly reduced in the acid rain treated plants and their number was highest in pre-inoculation treatment and lowest in post-inoculation treatment of acid rains. The acid rain of pH 3.2 was more effective than of pH 5 in all the treatments (Table 6).

Table 6. Interactive effects of simulated acid rain, root-knot nematodes and root nodule bacteria on root galling, eggmass production and root nodulation on chick-pea.

Treatment		Gall/Eggmass								Nodule							
		pH 5			pH 3.2			L.S.D.		pH 5				pH 3.2			L.S.D.
		C	Pe	S	Pt	Pe	S	Pt	0.01	0.05	C	Pe	S	Pt	Pe	S	Pt	0.01	0.05
P (Control)																			
P+Rh											T 140.4	107.6	105.8	104.6	55.2	54.6	54.2	9.59	6.34
											F 120.6	92.8	92.2	91.4	39.2	39.2	38.6	8.27	6.10
											I -	-	-	-	-	-	-	-	-
P+Mi	G	176.2	145.2	160.4	167.2	73.4	79.4	84.0	8.50	6.27									
	E	108.6	91.2	95.2	98.4	36.8	37.2	39.4	6.30	4.65									
P+Rh+Mi	G	125.6	102.6	115.0	121.8	57.2	62.6	68.2	7.83	5.78	T 100.2	83.4	80.2	76.6	47.6	45.2	41.4	9.31	6.87
	E	86.4	65.4	69.8	73.6	28.2	30.4	32.2	4.76	3.51	F 70.8	64.6	60.0	56.4	31.8	30.0	27.2	6.67	4.92
											I 15.2	11.4	11.2	9.6	6.4	6.0	6.0	1.48	1.09
P+Mj	G	83.4	70.4	77.6	79.4	35.2	39.6	41.2	5.66	4.18									
	E	48.6	41.2	43.4	44.6	18.8	19.2	20.4	3.90	2.88									
P+Rh+Mj	G	52.2	43.8	48.6	51.8	24.2	27.2	29.4	5.17	3.82	T 125.4	97.6	93.6	88.2	52.4	50.2	45.6	8.32	6.14
	E	33.4	26.4	28.2	29.0	12.4	13.2	14.2	3.56	2.63	F 100.6	80.8	76.4	70.2	36.6	34.8	31.2	7.22	5.33
											I 11.2	9.8	9.2	8.0	5.4	5.0	4.8	1.14	0.84
L.S.D.																			
0.01	G	8.05	7.54	8.51	7.74	8.16	5.22	4.91			T 18.46	8.26	8.31	7.55	4.18	4.38	3.34		
	E	7.40	6.48	6.32	6.79	3.59	3.34	3.49			F 13.30	6.39	6.05	6.17	2.17	2.30	2.14		
											I 3.17	1.24	1.14	1.16	0.65	0.70	0.63		
0.05	G	5.74	5.38	6.07	5.52	3.68	3.72	3.50			T 12.69	5.68	5.71	5.19	2.87	3.01	2.09		
	E	5.28	4.62	4.51	4.84	2.56	2.38	2.49			F 9.14	4.39	4.16	4.24	4.49	1.58	1.47		
											I 1.91	0.75	0.69	0.70	0.39	0.42	0.38		

G = Gall, E = Eggmass

T = Total, F = Functional, I = Infected

Each value is mean of five replicates.

Leaf pigments and seed proteins

Leaf pigments and seed proteins were reduced by the simulated acid rains. The effects of acid rain of pH 3.2 were significantly greater than of pH 5. In comparison to control, the reduction in pigment content of leaves caused by acid rain of pH 3.2 was significant at $P = 0.01$ and by the pH 5 was significant at $P = 0.05$. The protein content of seeds were reduced by both the pH levels of acid rain. The increase in the chlorophyll content of leaves and protein content of seeds caused by application of Rhizobium was suppressed by the acid rains. The acid rain of pH 3.2 was more effective than of pH 5 in this respect. Effect of the nematode inoculations alone or along with Rhizobium on chlorophyll content of leaves and protein content of seeds were influenced by the acid rains. Among the three timings of acid rain applications, the chlorophyll and protein contents were highest in pre-inoculation and lowest in post-inoculation treatments of the acid rains (Table 7, Figs. 1C and 1D).

Leaf epidermal characters

The various leaf epidermal characters on both the leaf surfaces were affected by the acid rains. The number of stomata, size of stomata and stomatal aperture, the number and length of trichome-hydathodes were reduced.

Table 7. Interactive effects of simulated acid rain, root-knot nematodes and root nodule bacteria on chlorophyll content of leaves and protein content of seeds of chick-pea.

Treatment		Chlorophyll (mg/g)									Protein (%)								
		pH 5			pH 3.2			L.S.D.			pH 5				pH3.2			L.S.D.	
		C	Pe	S	Pt	Pe	S	Pt	0.01	0.05	C	Pe	S	Pt	Pe	S	Pt	0.01	0.05
P (Control)	A	0.621	0.585	0.585	0.588	0.365	0.363	0.365	0.042	0.031	S 11.30	10.34	10.34	10.32	8.54	8.54	8.54	0.50	0.37
	B	0.571	0.529	0.529	0.531	0.326	0.325	0.326	0.039	0.029	I 14.36	13.84	13.84	13.84	11.98	11.96	11.98	0.65	0.48
	T	1.313	1.236	1.236	1.238	0.770	0.768	0.770	0.083	0.061	T 25.66	24.18	24.18	24.16	20.52	20.50	20.50	0.99	0.73
P+Rh	A	0.943	0.844	0.844	0.844	0.443	0.441	0.443	0.066	0.049	S 12.34	11.06	11.04	11.06	8.86	8.84	8.86	0.57	0.42
	B	0.878	0.767	0.768	0.767	0.389	0.394	0.398	0.054	0.040	I 15.62	14.80	14.80	14.82	12.34	12.32	12.34	0.64	0.47
	T	1.901	1.783	1.785	1.783	0.935	0.932	0.935	0.102	0.075	T 27.96	25.86	25.84	25.88	21.24	21.16	21.20	1.26	0.93
P+Mi	A	0.447	0.521	0.519	0.514	0.351	0.348	0.345	0.035	0.026	S 10.94	10.04	9.98	9.96	**9.28**	9.22	9.18	0.45	0.33
	B	0.412	0.470	0.468	0.464	0.313	0.310	0.308	0.028	0.021	I 13.96	13.44	13.40	13.36	**13.06**	12.92	12.84	0.61	0.45
	T	0.945	1.101	1.096	1.087	0.741	0.734	0.728	0.058	0.043	T 24.90	23.48	23.38	23.32	**22.34**	22.14	22.02	1.14	0.84
P+Rh+Mi	A	0.612	0.685	0.672	0.656	0.392	0.385	0.378	0.050	0.037	S 11.40	10.34	10.30	10.26	8.60	8.54	8.52	0.66	0.49
	B	0.559	0.621	0.609	0.594	0.351	0.345	0.338	0.043	0.032	I 14.38	13.88	13.78	13.74	11.98	11.96	11.92	0.84	0.62
	T	1.285	1.447	1.419	1.385	0.828	0.813	0.798	0.096	0.071	T 25.78	24.22	24.08	24.00	20.58	20.50	20.44	1.33	0.98
P+Mj	A	0.520	0.568	0.566	0.563	0.361	0.369	0.358	0.038	0.028	S 11.10	10.14	10.08	10.02	8.44	8.44	8.40	0.58	0.43
	B	0.479	0.518	0.511	0.509	0.223	0.321	0.320	0.039	0.029	I 14.06	13.56	13.54	13.48	11.88	11.82	11.74	0.62	0.46
	T	1.094	1.281	1.195	1.189	0.763	0.759	0.755	0.084	0.062	T 25.16	23.70	23.62	23.50	20.32	20.26	20.14	1.04	0.77
P+Rh+Mj	A	0.729	0.792	0.777	0.762	0.425	0.419	0.414	0.047	0.035	S 11.68	10.58	10.52	10.44	8.64	8.58	8.56	0.65	0.48
	B	0.660	0.719	0.705	0.692	0.381	0.376	0.371	0.056	0.041	I 14.72	14.14	14.08	14.02	12.08	12.04	11.98	0.77	0.57
	T	1.539	1.673	1.641	1.610	0.896	0.885	0.873	0.094	0.069	T 26.40	24.72	24.60	24.46	20.72	20.62	20.54	1.54	1.14
L.S.D.																			
0.01	A	0.060	0.056	0.057	0.056	0.040	0.038	0.040			S 0.65	0.56	0.57	0.55	0.44	0.42	0.46		
	B	0.057	0.055	0.057	0.053	0.035	0.037	0.041			I 0.63	0.61	0.60	0.63	0.41	0.44	0.42		
	T	0.106	0.094	0.100	0.102	0.064	0.067	0.070			T 0.97	1.00	0.97	0.63	0.78	0.79	0.80		
0.05	A	0.044	0.041	0.042	0.041	0.029	0.028	0.029			S 0.48	0.41	0.42	0.40	0.32	0.31	0.29		
	B	0.042	0.040	0.042	0.039	0.026	0.027	0.030			I 0.46	0.45	0.44	0.46	0.30	0.32	0.31		
	T	0.078	0.069	0.073	0.075	0.047	0.049	0.051			T 0.71	0.73	0.71	0.74	0.57	0.58	0.59		

A = Chl.a, B= Chl.b, T = Total chl.

S = Soluble, I = Insoluble, T = Total

Each value is mean of five replicates.

The rain of pH 3.2 was more effective than of pH 5. The effects were greater on the upper surface than lower surface of leaves. Number of stomata, size of stomata and stomatal aperture on the upper surface of leaves were significantly reduced by acid rain pH 5. The reductions in these measures on lower surface were not significant. The number of stomata on upper surface and trichome-hydathodes on both surfaces of the leaves were significantly reduced. The reduction in the size of stomata and stomatal aperture on upper surface and the length of trichome-hydathodes on both the surfaces was significant at P = 0.05. The reductions in all these leaf epidermal characters due to rain of pH 3.2 were significant at P = 0.01. But reduction in the size of stomata on lower surface was significant only at P =0.05. The favourable effects of Rhizobium and adverse effects of either species of Meloidogyne, alone and in combination on the leaf epidermal characters, were suppressed by the acid rains. The suppression was greater by acid rain of pH 3.2 than of pH 5. There were no significant differences in the measures of epidermal characters between pre-, post- and simultaneous inoculations of the nematodes in relation to acid rain applications although the epidermal characters were highest and lowest in pre- and post-inoculation treatments of acid rains (pH 5 and 3.2), respectively (Table.8, 9 and 10).

Table 8. Interactive effects of simulated acid rain, root-knot nematodes and root nodule bacteria on number of stomata on leaves of chick-pea.

Treatment		Number of stomata / cm^2							
			pH 5			pH 3.2		L.S.D.	
		C	Pe	S	Pt	Pe	S	Pt	0.01	0.05
P (Control)	L	24992.12	24942.24	24940.39	24942.86	22515.42	22515.74	22516.83	729.40	538.25
	U	13884.45	13223.29	13213.14	13225.31	11766.48	11765.59	11767.84	597.98	441.27
P+Rh	L	30240.45	29182.42	29181.46	29184.59	25667.58	25665.34	25668.76	667.73	492.74
	U	17160.17	15603.48	15602.54	15604.67	13531.46	13531.28	13534.51	803.45	592.89
P+Mi	L	23140.26	23419.94	23310.50	23202.08	21859,63	21754.03	21649.45	658.98	486.28
	U	12451.02	12131.46	12076,06	12021.17	11313.93	11259.79	11206.17	613.70	452.87
P+Rh+Mi	L	25916.74	25761.95	25408.45	25290.27	23171.21	22841.73	22731.92	742.19	547.69
	U	14344.72	13708.54	13525.19	13403.50	12105.90	11935.38	11822.51	682.61	503.72
P+Mj	L	23801.36	24029.13	23982.92	23868.17	22292.50	22182.68	22073.95	648.53	478.57
	U	12879.11	12474.80	12416.22	12358.21	11535.77	11479.50	11423.77	626.22	462.11
P+Rh+Mj	L	27847.42	27633.50	27340.53	26971.03	24521.75	24179.13	23839.86	723.62	533.98
	U	15352.25	14470.77	14278.67	14088.36	12804.70	12627.45	12451.91	785.73	579.82
L.S.D.										
0.01	L	678.46	644.91	631.86	652.67	625.00	444.37	392.49		
	U	520.92	436.24	442.61	406.18	292.38	282.60	288.77		
0.05	L	497.46	472.86	463.29	478.55	311.62	325.82	287.78		
	U	381.91	319.86	324.93	297.82	214.38	207.21	211.73		

L = Lower surface, U = Upper surface

Each value is mean of five replicates.

Table 9. Interactive effects of simulated acid rain, root-knot nematodes and root nodule bacteria on size of stomata and stomatal aperture on leaves of chick-pea.

Treatment		Size of Stomata (μm^2)								Size of stomatal aperture (μm^2)							
		pH 5			pH 3.2			L.S.D.		pH 5			pH 3.2			L.S.D.	
		C	Pe	S	Pt	Pe	S	Pt	0.01	0.05	C	Pe	S	Pt	Pe	S	Pt	0.01	0.05
P	L	396.33	392.43	392.32	391.65	373.90	372.46	371.25	25.11	18.53	86.44	84.75	84.70	84.62	81.55	81.39	81.08	4.85	3.58
(Control)	U	378.45	360.43	360.39	360.86	344.05	344.16	343.83	21.40	15.79	62.50	60.10	60.25	59.74	57.87	57.64	57.15	2.74	2.02
P+Rh	L	459.74	447.34	446.83	446.72	403.81	403.94	403.32	28.17	20.79	96.81	93.22	93.18	93.25	86.44	86.58	86.13	4.73	3.49
	U	446.57	414.49	414.38	413.91	375.01	374.62	374.72	30.94	22.83	71.88	66.71	66.56	66.34	61.92	61.87	61.59	5.43	4.01
P+Mi	L	360.61	366.73	365.03	363.34	363.01	361.25	359.52	22.81	16.83	75.17	75.33	75.00	75.67	79.95	79.56	79.11	4.85	3.58
	U	340.94	332.19	330.67	327.66	330.81	329.23	327.66	18.46	13.62	53.65	53.18	52.72	52.26	56.18	55.91	55.64	3.63	2.68
P+Rh+Mi	L	402.27	399.74	394.23	392.41	377.53	372.09	368.50	26.09	19.25	81.19	79.85	78.75	78.40	82.75	81.94	81.15	5.03	3.71
	U	387.26	365.41	362.08	357.15	347.35	342.40	339.13	22.06	16.28	59.55	57.44	56.57	56.18	58.71	58.15	57.59	3.35	2.47
P+Mj	L	376.89	374.46	373.72	371.95	370.19	368.37	363.56	19.20	14.17	78.58	78.47	78.11	77.75	80.74	80.34	79.95	3.97	2.93
	U	352.69	341.54	340.03	338.43	337.30	335.65	334.02	23.06	17.02	55.31	54.53	54.14	53.66	56.74	56.46	56.18	2.91	2.15
P+Rh+Mj	L	429.65	419.37	414.83	409.14	396.11	390.47	386.73	24.83	18.32	86.59	84.75	83.57	82.80	84.78	83.56	82.75	4.31	3.18
	U	410.12	386.05	380.33	377.35	364.26	359.15	355.74	26.36	19.45	61.95	59.82	58.74	57.95	60.14	59.28	58.71	3.05	2.25
L.S.D.																			
0.01	L	29.42	23.47	27.05	30.03	20.01	18.29	24.88			7.80	6.63	7.02	6.71	4.35	4.47	4.19		
	U	31.48	26.53	26.40	26.31	21.59	22.87	19.58			6.59	4.98	5.16	5.06	3.90	4.04	3.96		
0.05	L	21.57	17.21	19.83	22.02	14.67	13.44	18.24			5.74	4.86	5.15	4.92	3.19	3.28	3.07		
	U	23.08	19.45	19.36	19.29	15.83	16.77	14.36			4.83	3.65	3.78	3.71	2.86	2.96	2.90		

L = Lower surface, U = Upper surface

Each value is mean of five replicates.

Table 10. Interactive effects of simulated acid rain, root-knot nematodes and root nodule bacteria on number and length of trichome-hydathodes on leaves of chick-pea.

Treatment		Number of trichome-hydathodes/cm^2								Length of trichome-hydathodes (μm)							
			pH 5			pH 3.2			L.S.D.			pH 5			pH 3.2			L.S.D.	
		C	Pe	S	Pt	Pe	S	Pt	0.01	0.05	C	Pe	S	Pt	Pe	S	Pt	0.01	0.05
P (Control)	L	651.39	620.37	620.11	620.76	592.17	592.22	592.46	30.57	22.26	424.00	411.65	410.87	411.93	388.99	388.71	387.94	18.78	13.86
	U	411.40	384.49	384.52	384.68	357.74	357.52	357.91	26.33	19.43	404.13	381.25	381.11	381.38	357.64	357.24	357.48	27.78	20.50
P+Rh	L	1097.02	992.59	992.64	992.68	740.22	740.20	740.71	74.30	54.83	562.22	531.15	530.94	530.18	435.67	435.21	435.42	26.71	19.71
	U	828.16	634.40	634.49	534.77	465.06	464.11	465.35	84.48	62.34	545.76	499.44	499.26	499.28	407.71	407.10	406.85	33.36	24.62
P+Mi	L	497.24	492.36	488.48	478.58	521.65	510.49	501.84	29.37	21.67	375.22	374.23	370.86	367.55	372.24	370.47	366.97	13.75	10.15
	U	304.74	300.38	395.76	291.28	309.73	303.17	298.12	30.59	22.57	351.42	343.47	340.41	337.39	338.99	337.39	334.24	23.43	17.29
P+Rh+Mi	L	721.3x	699.15	683.87	658.55	594.78	571.75	552.02	35.05	25.86	446.51	437.81	430.19	422.68	394.57	388.39	383.49	23.43	17.29
	U	52x.72	438.55	419.98	407.79	356.19	339.55	227.92	77.00	56.82	428.73	408.73	398.28	391.38	366.11	361.21	35x.29	25.88	19.10
P+Mj	L	552.33	544.19	539.45	534.80	553.43	540.79	533.49	23.57	17.39	388.90	384.72	382.93	381.16	379.50	377.6x	375.3x	13.32	9.83
	U	340.00	331.45	328.62	323.10	326.70	320.84	316.58	24.37	17.98	364.08	354.66	353.01	349.77	345.54	343.88	340.61	17.02	12.56
P+Rh+Mj	L	866.69	827.17	809.18	791.50	675.18	648.95	629.51	39.91	29.45	482.24	469.36	459.52	452.58	517.45	411.65	405.90	28.89	21.32
	U	782.14	523.70	509.36	491.11	411.65	394.65	379.90	98.14	72.42	460.56	439.77	430.68	423.23	387.07	378.27	371.26	30.40	22.43
L.S.D.																			
0.01	L	97.445	74.64	85.32	80.90	59.30	60.38	54.19			40.53	31.16	27.54	29.17	26.64	25.04	29.27		
	U	90.27	64.89	61.88	64.95	41.49	44.45	45.08			47.58	37.52	37.26	34.97	26.16	33.54	32.21		
0.05	L	71.45	54.73	62.56	59.32	43.48	44.27	39.73			29.72	22.85	20.19	21.39	19.53	18.36	21.46		
	U	66.19	47.58	45.37	47.62	30.42	32.59	33.05			34.89	27.51	27.32	25.64	21.38	24.59	23.62		

L = Lower surface, U= Upper surface

Each value is mean of five replicates.

Table 11. Interactive effects of simulated acid rain, root-knot nematodes and root nodule bacteria on number and length of trichomes on leaves of chick-pea.

Treatment		Number of trichomes/cm^2								Length of trichomes (µm)								
		pH 5			pH 3.2			L.S.D.		pH 5				pH 3.2			L.S.D.	
		C	Pe	S	Pt	Pe	S	Pt	0.01	0.05	C	Pe	S	Pt	Pe	S	Pt	0.01	0.05
P (Control)	L	3039.57	3161.15	3160.24	3161.26	3343.53	3342.98	3342.83	138.98	102.56	331.25	341.60	341.56	341.68	366.71	366.45	366.27	25.27	18.65
	U	1651.24	1766.83	1766.72	1766.39	1898.93	1818.76	1898.14	110.10	81.25	320.75	338.06	338.99	338.93	363.80	363.69	363.27	22.21	16.39
P+Rh	L	1885.59	2039.45	2039.16	2038.75	2746.60	2740.51	2739.25	185.40	136.81	238.65	252.73	251.62	252.06	255.99	255.32	255.09	16.84	12.43
	U	788.62	1125.37	1125.09	1124.83	1460.71	1460.46	1460.07	106.36	78.49	230.11	248.95	248.62	248.59	295.80	295.37	295.32	18.62	13.74
P+Mi	L	3556.30	3572.10	3603.71	3635.33	3460.55	3477.27	3510.70	131.77	97.24	371.00	362.72	364.38	366.03	315.91	317.45	318.98	30.38	22.42
	U	2030.73	2067.19	2084.86	2120.19	1993.87	2012.86	2031.85	80.81	59.63	380.93	380.28	381.98	385.39	383.30	385.13	388.80	12.96	9.56
P+Rh+Mi	L	2894.17	2769.07	2837.57	2908.26	3142.96	3190.15	3250.65	160.66	118.56	304.10	302.26	306.20	310.19	282.07	285.99	289.98	23.47	17.32
	U	1430.09	1476.76	1511.72	1547.59	1669.72	1735.23	1766.83	91.49	67.51	322.82	325.62	332.29	335.12	336.23	343.87	350.27	16.27	12.08
P+J	L	3373.92	3414.05	3429.85	3461.46	3393.68	3410.40	3427.12	116.83	86.21	361.06	354.44	356.09	357.75	309.78	311.31	312.85	28.11	20.74
	U	1985.16	1978.85	1998.51	2014.18	2040.70	1955.89	1974.88	95.37	70.38	367.68	366.63	370.04	373.46	375.96	377.80	376.63	13.89	10.25
P+Rh+Mj	L	2249.28	2322.48	2365.41	2420.60	2876.00	2940.05	2980.10	172.60	127.37	284.29	283.55	287.17	290.85	264.77	268.37	272.04	20.81	15.36
	U	1212.43	1284.96	1319.50	1342.79	1540.24	1577.33	1605.60	115.81	85.46	285.02	286.43	293.69	298.76	313.30	320.17	324.47	19.55	14.43
L.S.D.																			
0.01	L	173.80	153.22	158.02	149.66	138.54	146.78	127.49			31.04	26.76	30.80	27.05	21.45	22.16	19.52		
	U	171.41	172.46	167.49	162.75	139.09	152.38	147.99			37.38	35.43	35.09	35.56	26.70	24.02	28.40		
0.05	L	127.43	112.34	115.86	109.73	101.58	107.62	93.48			22.76	19.62	22.58	19.83	15.73	16.25	14.31		
	U	125.68	126.45	122.81	119.33	108.58	111.73	108.51			27.41	25.98	25.73	26.07	19.58	17.61	20.82		

L = Lower surface, U = Upper surface

Each value is mean of five replicates.

The trichomes on the leaves of chick-pea responded positively to acid rain treatments and their number and length significantly increased. The increase in the number and length of trichomes due to pH 3.2 rain was significant at P = 0.01 on both the surfaces. Acid rain of pH 5 significantly (at P = 0.01) increased the number of trichomes on both the leaf surfaces and trichome length on the upper surface. The increase in length of trichome on lower surface was not significant. The reducing effect of Rhizobium in the measures of trichomes was suppressed by the acid rains. The response of trichomes as a result of M. incognita and M. javanica infection of plants, in the form of their increased number and length, and the responses of trichomes on plants inoculated with root-knot nematodes and Rhizobium were suppressed by acid rain applications. There was no marked difference between pre-, post- and simultaneous inoculation of the nematodes and acid rain applications, in these respects. The number and length of trichomes were highest in post-inoculation treatments of acidified rain and were lowest in pre-inoculation treatments of acid rain of both the pH. On epidermal characters, the impact of acid rain of pH 3.2 was more than acid rain of pH 5 (Table 11).

LENTIL, Lens culinaris Medic.

Plant growth and yield

Simulated acid rains of pH 3.2 and 5 adversely

Table 12. Interactive effects of simulated acid rain, root-knot nematodes and root nodule bacteria on plant length and fresh weight of lentil.

Treatment		Length (cm)								Fresh weight (g)								
			pH 5			pH 3.2			L.S.D.			pH 5			pH 3.2			L.S.D.	
		C	Pe	S	Pt	Pe	S	Pt	0.01	0.05	C	Pe	S	Pt	Pe	S	Pt	0.01	0.05
P (Control)	S	31.4	28.4	28.6	28.6	19.7	19.7	19.6	2.90	2.14	16.50	14.75	14.75	14.75	9.30	9.30	9.35	1.80	1.33
	R	17.0	15.7	15.7	15.8	12.6	12.6	12.8	1.69	1.25	12.50	11.35	11.35	11.40	7.80	7.80	7.80	1.22	0.90
P+Rh	S	38.7	34.1	34.1	34.3	21.3	21.2	21.2	3.59	2.65	23.75	20.50	20.50	20.55	11.15	11.15	11.20	2.43	1.79
	R	21.5	18.5	18.4	18.4	13.4	13.4	13.5	2.39	1.76	19.60	17.00	17.05	17.05	9.75	9.75	9.80	1.68	1.24
P+Mi	S	24.2	22.6	22.4	22.2	17.3	17.1	16.9	2.63	1.94	12.95	12.20	11.95	11.80	8.75	8.65	8.60	0.98	0.72
	R	13.3	12.5	12.4	12.3	10.9	10.8	10.7	1.18	0.87	8.75	8.25	8.10	7.95	7.35	7.30	7.20	0.81	0.60
P+Rh+Mi	S	27.5	25.5	25.1	25.6	17.9	17.6	17.5	2.15	1.59	16.40	15.10	14.60	14.15	9.45	9.25	9.10	1.60	1.18
	R	15.4	14.1	13.9	13.7	13.2	11.0	10.9	1.28	1.02	11.35	10.70	10.40	10.00	8.40	8.15	7.95	1.12	0.83
P+Mj	S	28.8	24.9	24.7	24.5	19.1	19.0	18.9	3.21	2.37	14.50	13.40	13.25	13.15	9.10	9.05	8.95	1.06	0.78
	R	16.5	15.4	15.3	15.3	12.6	12.5	12.4	1.26	0.93	10.45	9.85	9.80	9.70	7.55	7.55	7.50	0.77	0.57
P+Rh+Mj	S	32.4	28.9	28.4	27.9	20.5	20.2	19.8	2.95	2.18	19.85	17.95	17.50	17.10	10.35	10.10	10.00	1.72	1.27
	R	19.7	17.9	17.6	17.5	13.4	13.2	13.1	1.18	0.87	14.50	13.20	12.95	12.65	9.10	8.90	8.70	1.68	1.24
L.S.D.																			
0.01	S	2.92	2.84	2.88	2.91	2.40	2.25	2.21			1.83	1.70	1.61	1.66	1.46	1.27	1.31		
	R	1.62	1.54	1.46	1.45	1.19	1.25	1.13			1.62	1.58	1.57	1.60	1.06	1.13	1.28		
0.05	S	2.14	2.08	2.11	2.13	1.76	1.65	1.62			1.34	1.25	1.18	1.22	1.07	0.93	0.96		
	R	1.19	1.13	1.07	1.06	0.87	0.92	0.83			1.19	1.16	1.15	1.17	0.78	0.83	0.94		

S = Shoot, R = Root

Each value is mean of five replicates.

Table 13. Interactive effects of simulated acid rain, root-knot nematodes and root nodule bacteria on dry weight, flowering and fruiting of lentil.

Treatment		Dry weight (g)									Flowers/Fruits							
		pH 5			pH 3.2			L.S.D.			pH 5			pH 3.2			L.S.D.	
		C	Pe	S	Pt	Pe	S	Pt	0.01	0.05	C	Pe	S	Pt	Pe	S	Pt	0.01	0.05
P (Control)	S	3.15	2.90	2.90	2.95	2.15	2.15	2.10	0.23	0.17	FL 52.4	44.2	44.2	44.6	18.8	18.8	19.0	4.40	3.25
	R	2.85	2.70	2.70	2.75	1.95	1.90	1.95	0.18	0.13	FR 35.8	29.2	29.2	29.4	11.2	11.2	11.4	2.93	2.16
P+Rh	S	4.65	4.00	4.00	4.00	2.60	2.60	2.65	0.42	0.31	FL 80.2	63.4	65.2	63.4	22.6	22.6	22.8	7.94	5.86
	R	4.25	4.05	4.00	4.00	2.40	2.40	2.45	0.39	0.29	FR 60.2	45.0	45.2	48.6	13.4	13.4	13.8	6.75	6.93
P+Mi	S	2.55	2.40	2.35	2.35	2.05	2.00	1.95	0.18	0.13	FL 42.2	37.0	36.6	36.4	17.4	17.2	17.0	3.74	2.76
	R	2.35	1.95	1.90	1.85	1.80	1.80	1.75	0.14	1.10	FR 26.4	22.8	22.4	22.2	10.6	10.4	10.4	2.87	2.12
P+Rh+Mi	S	3.25	3.05	2.90	2.80	2.20	2.15	2.10	0.27	0.20	FL 57.4	48.6	47.4	46.6	19.4	18.8	18.6	5.64	4.16
	R	3.15	2.55	2.50	2.45	2.10	2.05	1.95	0.28	0.21	FR 39.4	33.2	33.2	30.8	11.8	11.4	11.2	3.84	2.83
P+Mj	S	2.80	2.60	2.60	2.55	2.10	2.10	2.05	0.22	0.16	FL 47.2	41.6	41.4	41.2	18.4	18.2	18.2	4.32	3.19
	R	2.55	2.20	2.30	2.25	1.90	1.85	1.85	0.16	0.12	FR 31.4	27.6	27.0	27.0	10.8	10.8	10.8	3.28	2.42
P+Rh+Mj	S	3.90	3.60	3.50	3.45	2.40	2.35	2.30	0.33	0.24	FL 67.4	57.4	56.2	34.8	21.4	21.2	20.6	7.68	5.67
	R	3.55	3.15	3.10	3.00	2.30	2.25	2.20	0.20	0.22	FR 49.2	40.8	39.8	38.8	12.8	12.7	12.2	5.54	4.09
L.S.D.																			
0.01	S	0.40	0.37	0.35	0.41	0.38	0.30	0.26			FL 7.80	4.31	4.21	4.27	2.61	2.78	2.69		
	R	0.30	0.26	0.26	0.23	0.18	0.15	0.14			FR 4.69	4.20	3.91	4.17	1.70	1.66	1.77		
0.05	S	0.34	0.27	0.26	0.30	0.28	0.22	0.19			FL 5.72	3.16	3.09	3.13	1.90	2.04	1.97		
	R	0.22	0.19	0.19	0.17	0.13	0.11	0.10			FR 3.44	3.08	2.87	3.06	1.25	1.22	1.30		

S = Shoot, R = Root

FL = Flower, FR = Fruit

Each value is mean of five replicates.

affected plant growth and flowering and fruiting of lentil as well. The reductions by the acid rains of pH 3.2 and 5 were significant at P = 0.01 except the reductions caused by acid rain of pH 5 in root length and fresh weight of shoot and root and dry weight of root which were, however, significant at P = 0.05. The favourable effects of Rhizobium and decreasing effects of M. incognita and M. javanica on the growth and yield parameters of lentil were reduced by the acid rains. The interactive effects of M. incognita and M. javanica with Rhizobium were variously influenced by the acid rains. Poorest plant growth were observed when acid rain and the nematode (either species of Meloidogyne) were present. Plant growth and yield parameters were highest in pre-inoculation treatments of acid rain and were lowest in post-inoculation treatments. The differences between pre-, post- and simultaneous inoculation treatments of acid rains in both the pH were, however, not significant. In all the treatments of acid rain the rain of pH 3.2 was invariably more effective in causing various adverse effects than acid rain of pH 5 (Tables 12 and 13, Figs. 2A and 2B).

Root-knot disease and root nodulation

Simulated acid rains of both pH levels suppressed root galling and eggmass production of M. incognita and M. javanica on lentil significantly. The reductions in the number of galls and eggmasses of M. incognita and M. javanica due to interaction with Rhizobium were affected

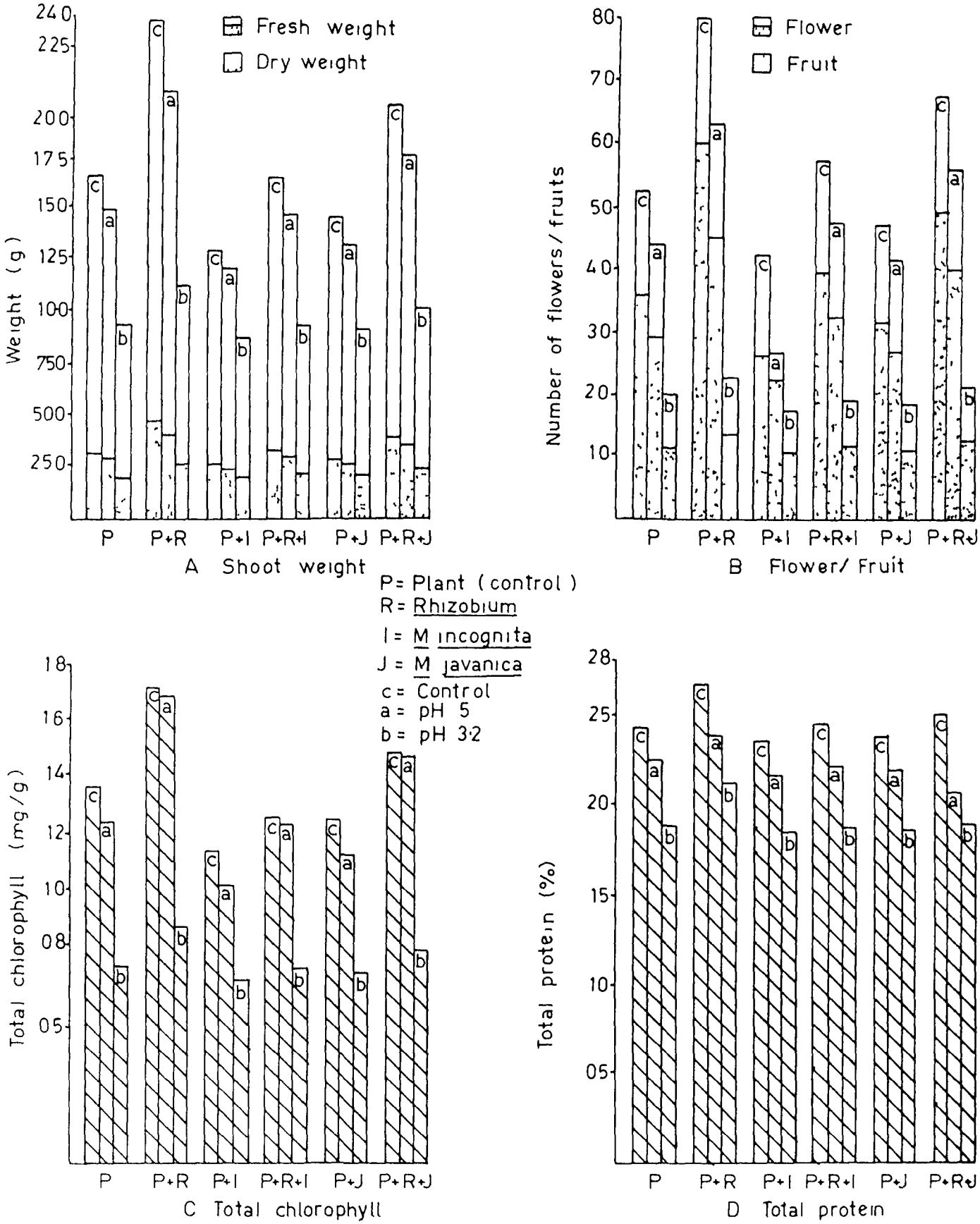

Fig 2 Interactive effects of simulated acid rain, root-knot nematodes and root nodule bacteria on some parameters of lentil in simultaneous inoculation treatment

by the acid rains. Poorest root galling and eggmass production of both species of Meloidogyne occurred, when the root-knot nematode and Rhizobium inoculated plants were exposed to acid rains. The number of galls and eggmasses were greater in post-inoculation treatment than in simultaneous or pre-inoculation treatment of acid rains (Table 14).

As in chick-pea, root nodulation of lentil was also adversely affected by the simulated acid rains. Total number of nodules and the functional nodules decreased significantly by both the pH of rains. The adverse effects of M. incognita and M. javanica, which caused reductions in total number of nodules and number of functional nodules were influenced by the acidified rains. Poorest root nodulation was observed when M. incognita inoculated plants were treated with acid rain.The number of nodules infected with the nematodes was also reduced by the acid rains. Number of total nodules, functional nodules and the infected nodules were highest in pre-inoculation treatment and lowest in post-inoculation treatment of acid rains. Invariably in all the treatments, pH 3.2 acid rain was more effective than acid rain of pH 5 (Table 14).

Leaf pigments and seed proteins

Leaf pigment and seed protein contents were significantly reduced by the simulated acid rains in lentil plants

Table 14. Interactive effects of simulated acid rain, root-knot nematodes and root nodule bacteria on root galling, eggmass production and root nodulation on lentil.

Treatment		Gall/Eggmass C	pH 5 Pe	pH 5 S	pH 5 Pt	pH 3.2 Pe	pH 3.2 S	pH 3.2 Pt	L.S.D. 0.01	L.S.D. 0.05	Nodule C	pH 5 Pe	pH 5 S	pH 5 Pt	pH 3.2 Pe	pH 3.2 S	pH 3.2 Pt	L.S.D. 0.01	L.S.D. 0.05
P																			
P+Rh											T 226.4	163.4	162.8	162.6	61.4	61.4	61.0	22.79	16.82
											F 203.2	136.2	137.0	135.6	42.0	41.6	41.4	23.84	17.59
											I -	-	-	-	-	-	-	-	-
P+Mi	G	136.4	106.8	110.2	125.4	46.4	49.6	55.2	15.54	11.47									
	E	93.2	74.4	77.8	82.2	16.2	17.4	17.6	11.72	8.65									
P+Rh+Mi	G	107.2	91.2	96.6	101.2	39.2	43.8	47.4	17.01	12.55	T 154.6	128.6	123.2	115.4	51.2	50.4	49.2	13.06	9.64
	E	70.6	59.8	63.2	67.4	13.8	15.2	15.8	9.11	6.72	F 110.4	97.4	91.2	83.6	33.6	32.6	21.4	9.82	7.25
											I 25.8	21.6	19.8	18.8	10.4	8.6	8.2	2.24	1.65
P+Mj	G	64.4	55.4	57.6	60.4	30.4	25.6	28.2	9.40	6.94									
	E	37.8	31.6	32.2	33.8	9.2	10.8	10.4	4.63	3.42									
P+Rh+Mj	G	52.8	45.2	47.0	51.8	20.4	22.2	25.8	6.55	4.83	T 196.0	142.2	139.4	132.6	58.4	58.0	55.2	17.45	12.88
	E	34.2	25.2	28.4	28.2	8.4	9.2	9.6	5.57	4.11	F 151.4	113.8	109.6	102.4	39.4	38.8	36.6	13.16	9.72
											I 16.4	12.4	11.2	10.4	8.4	8.2	7.6	0.99	0.73
L.S.D.																			
0.01	G	12.24	8.22	7.68	7.89	2.63	3.91	3.58			T 23.77	8.79	8.61	8.89	4.77	4.82	4.60		
	E	7.89	5.73	5.65	5.83	1.58	1.68	1.63			F 24.08	7.74	6.23	6.82	3.56	3.14	3.20		
											I 4.10	2.17	1.92	1.97	0.71	0.63	0.70		
0.05	G	8.73	8.86	8.48	5.63	2.59	2.79	2.55			T 16.34	6.04	8.92	6.11	3.28	3.31	3.16		
	E	5.63	4.09	4.03	4.16	1.13	1.20	1.16			F 16.55	5.32	4.28	2.69	2.45	2.16	2.20		
											I 2.45	2.31	1.16	1.19	0.43	0.38	0.42		

G = Gall, E = Eggmass

T = Total, F = Functional, I = Infected

Each value is mean of five replicates.

receiving no treatment of Rhizobium and the nematodes. But the reduction in chlorophyll a and total chlorophyll contents was significant only at P = 0.05. The increasing effect of Rhizobium on the pigment content of leaves and protein content of seeds was also suppressed by the acid rains. The reducing effects of M. incognita and M. javanica on pigment content of leaves and protein content of seeds were influenced by the acid rains. Relatively less reductions were caused by the nematodes in these measures because of acid rain applications. The effects on leaf pigments and seed proteins in the presence of root nodule bacteria and M. javanica or M. incognita were further reduced by the acid rain applications. The chlorophyll content of leaves in plants inoculated with Rhizobium and root-knot nematode and exposed to acid rain was greater than the exposed plants without any inoculation or to the root-knot nematode inoculated plants. The leaf pigments and seed proteins were highest in pre-inoculation treatments of acid rain and lowest in post-inoculation treatments. In all the treatments, comparatively acid rain of pH 3.2 was more effective than of pH 5 (Table 15, Figs. 2C and 2D).

Leaf epidermal characters

Simulated acid rains adversely affected leaf epidermal characters of lentil. The stomatal count and size were

Table 15. Interactive effects of simulated acid rain, root-knot nematodes and root nodule bacteria on chlorophyll content of leaves and protein content of seeds of lentil.

Treatment		Chlorophyll (mg/g)									Protein (%)								
		pH 5			pH 3.2			L.S.D.			pH 5				pH 3.2			L.S.D.	
		C	Pe	S	Pt	Pe	S	Pt	0.01	0.05	C	Pe	S	Pt	Pe	S	Pt	0.01	0.05
P (Control)	A	0.724	0.656	0.658	0.656	0.381	0.382	0.382	0.073	0.054	S 10.46	9.58	9.58	9.58	7.72	7.72	7.74	0.34	0.25
	B	0.565	0.503	0.505	0.503	0.289	0.391	0.293	0.058	0.043	I 13.94	13.00	13.00	13.00	11.18	11.18	11.20	0.38	0.28
	T	1.362	1.236	1.238	1.236	0.718	0.719	0.718	0.154	0.114	T 24.40	22.58	22.58	22.58	18.90	18.90	18.94	0.87	0.64
P+Rh	A	0.902	0.908	0.907	0.910	0.451	0.453	0.452	0.062	0.046	S 11.56	10.18	10.20	10.20	9.90	9.92	9.92	0.28	0.21
	B	0.714	0.699	0.697	0.720	0.344	0.345	0.345	0.056	0.041	I 15.28	13.84	13.84	13.80	11.40	11.44	11.44	0.61	0.45
	T	1.716	1.690	1.688	1.693	0.852	0.855	0.857	0.115	0.085	T 26.84	24.02	24.04	24.00	21.30	21.36	21.36	0.80	0.59
P+Mi	A	0.594	0.544	0.535	0.527	0.357	0.354	0.350	0.062	0.046	S 10.16	9.30	9.24	9.18	7.64	7.60	7.58	1.06	0.78
	B	0.457	0.416	0.409	0.402	0.270	0.268	0.265	0.057	0.042	I 13.52	12.72	12.60	12.44	11.06	11.04	10.98	1.14	0.84
	T	1.129	1.025	1.009	0.993	0.672	0.666	0.660	0.120	0.089	T 23.68	22.02	21.84	21.62	18.70	18.64	18.56	1.45	1.07
P+Rh+Mi	A	0.648	0.672	0.651	0.630	0.384	0.378	0.371	0.053	0.039	S 10.60	9.56	9.44	9.34	7.74	7.74	7.68	0.76	0.56
	B	0.496	0.515	0.499	0.483	0.292	0.286	0.281	0.061	0.045	I 14.02	12.98	12.82	12.72	11.22	11.18	11.16	0.65	0.48
	T	1.252	1.266	1.226	1.187	0.725	0.712	0.699	0.111	0.082	T 24.62	22.54	22.26	22.06	18.96	18.92	18.84	1.65	1.22
P+Mj	A	0.664	0.597	0.592	0.587	0.370	0.370	0.367	0.069	0.051	S 10.26	9.42	9.34	9.22	7.68	7.62	7.60	0.98	0.72
	B	0.503	0.457	0.553	0.449	0.281	0.281	0.278	0.051	0.038	I 13.66	12.82	12.72	12.62	11.12	11.08	11.06	0.53	0.39
	T	1.244	1.125	1.115	0.913	0.698	0.698	0.691	0.103	0.076	T 23.92	22.24	22.06	21.84	18.80	18.70	18.66	1.17	0.86
P+Rh+Mj	A	0.780	0.796	0.778	0.759	0.431	0.413	0.402	0.462	0.046	S 10.88	9.76	9.68	9.58	7.76	7.74	7.70	0.72	2.53
	B	0.523	0.613	0.598	0.584	0.320	0.314	0.306	0.058	0.043	I 14.24	13.26	13.16	13.04	11.24	11.22	11.18	0.53	0.39
	T	1.448	1.501	1.466	1.181	0.793	0.779	0.758	0.126	0.093	T 25.12	23.02	22.84	22.62	19.00	18.96	18.88	1.60	1.18
L.S.D.																			
0.01	A	0.079	0.063	0.065	0.067	0.042	0.044	0.046			S 0.40	0.35	0.37	0.38	0.29	0.30	0.30		
	B	0.059	0.052	0.057	0.053	0.035	0.037	0.038			I 0.34	0.38	0.35	0.34	0.31	0.29	0.31		
	T	0.139	0.119	0.115	0.108	0.090	0.094	0.100			T 0.81	0.80	0.76	0.82	0.70	0.67	0.68		
0.05	A	0.058	0.046	0.048	0.059	0.031	0.032	0.034			S 0.29	0.26	0.27	0.28	0.21	0.22	0.22		
	B	0.043	0.038	0.042	0.039	0.026	0.027	0.028			I 0.25	0.28	0.26	0.25	0.23	0.21	0.23		
	T	0.102	0.087	0.093	0.079	0.066	0.069	0.073			T 0.62	0.59	0.56	0.60	0.51	0.49	0.50		

A = Chl.a, B = Chl.b, T = Total chl.

S = Soluble, I = Insoluble, T = Total

Each value is mean of five replicates.

reduced significantly by acid rain of pH 3.2. Reduction in size of stomata was significant at P = 0.05 and P = 0.01 on the lower and upper leaf surface respectively. The favourable response of epidermal characters by the presence of Rhizobium was diminished by the simulated acid rains. The effects of M. incognita and M. javanica alone and in combination with Rhizobium were also suppressed by simulated acid rains. The suppressive effect of acid rain of pH 3.2 was greater than pH 5. The number of stomata and the size of stomata and stomatal aperture were highest in pre-inoculation treatment of acid rain and were lowest in post-inoculation treatment of acid rains in relation to nematode inoculation (Table 16 and 17).

The trichomes on lentil leaves responded positively to acid rains and their number and length significantly increased. The increase in the length of trichomes on lower surface was only significant at P = 0.05. The decreasing effects of Rhizobium and increasing effects of M. incognita and M. javanica or the combined effects of the root-knot nematodes and Rhizobium on trichomes were suppressed by the acid rains. The number and length of trichomes were lowest in pre-inoculation treatment and highest in post-inoculation treatment of acid rains (Table 18).

Table 16. Interactive effects of simulated acid rain, root-knot nematodes and root nodule bacteria on number of stomata on leaves of lentil.

Treatment		Number of stomata / cm^2							
			pH 5			pH 3.2		L.S.D.	
		C	Pe	S	Pt	Pe	S	Pt	0.01	0.05
P (Control)	L	4936.83	4818.35	4816.42	4818.24	4368.92	4368.88	4369.55	168.61	124.42
	U	3538.06	3418.46	3418.42	3420.17	3076.84	3076.57	3076.92	150.04	102.72
P+Rh	L	5430.51	5249.78	5249.90	5250.46	4543.78	4543.63	4545.29	164.95	121.72
	U	2963.18	3760.59	3760.26	3761.88	3131.25	3230.40	3231.78	163.77	120.85
P+Mi	L	4485.03	4480.39	4459.62	4418.73	4180.74	4160.83	4121.58	133.17	98.27
	U	3173.15	3164.20	3150.61	3121.84	2902.43	2888.80	2875.30	95.62	70.56
P+Rh+Mi	L	4754.13	4749.21	4704.93	4639.67	4264.36	4235.73	4183.41	106.54	78.62
	U	3458.73	3418.42	3386.91	3355.98	2989.50	2961.02	2932.81	87.07	64.25
P+Mj	L	4813.86	4747.07	4565.33	4543.79	4283.21	4262.32	4241.63	111.37	82.18
	U	3251.89	3209.78	3194.78	3179.92	2986.97	2972.54	2958.54	127.89	94.36
P+Rh+Mj	L	5028.17	4954.03	4907.73	4884.58	4454.52	4411.50	4390.08	145.39	107.29
	U	3659.08	3498.66	3466.34	3434.32	3121.38	3091.44	3076.57	100.93	74.48
L.S.D.										
0.01	L	228.43	170.25	176.28	179.73	143.68	131.71	138.20		
	U	176.70	150.61	146.29	151.28	134.72	121.98	127.56		
0.05	L	167.59	124.83	129.25	131.78	105.35	96.57	101.33		
	U	129.56	110.43	107.26	110.92	98.78	89.44	93.53		

L = Lower surface, U = Upper surface

Each value is mean of five replicates.

Table 17. Interactive effects of simulated acid rain, root-knot nematodes and root nodule bacteria on size of stomata and stomatal aperture on leaves of lentil.

Treatment		Size of stomata (μm^2)								Size of stomatal aperture (μm^2)								
		PH 5			PH 3.2			L.S.D.		PH 5				PH 3.2			L.S.D.	
		C	Pe	S	Pt	Pe	S	Pt	0.01	0.05	C	Pe	S	Pt	Pe	S	Pt	0.01	0.05
P (Control)	L	660.44	635.14	635.04	635.56	605.97	605.91	606.38	29.85	22.03	86.44	83.90	83.92	84.10	80.07	80.04	80.25	5.08	3.75
	U	591.12	563.28	562.97	563.70	537.72	537.38	537.91	26.40	19.48	69.15	66.50	66.58	66.64	65.15	65.24	63.45	4.32	3.19
P+Rh	L	713.28	673.23	673.14	673.89	624.25	624.09	625.03	33.02	24.37	92.49	89.09	88.96	89.22	82.59	82.44	82.48	4.99	3.68
	U	656.14	608.35	608.01	608.92	558.57	558.88	559.43	30.42	22.45	75.37	71.14	71.21	71.32	65.68	65.78	65.95	4.40	3.25
P+Mi	L	582.91	574.70	572.11	564.00	574.32	571.61	568.93	32.31	23.84	77.18	76.64	76.29	75.61	76.96	76.59	76.23	5.31	3.92
	U	517.62	504.91	502.65	498.20	506.96	504.98	502.23	32.92	24.29	60.66	59.90	59.37	58.84	60.43	60.14	59.58	4.68	3.45
P+Rh+Mi	L	609.14	591.94	589.27	581.17	585.81	580.19	577.46	38.51	28.42	80.26	78.94	78.20	77.50	78.50	77.74	77.73	5.20	3.84
	U	548.67	530.15	525.27	520.62	517.10	512.15	509.76	39.77	29.35	63.39	62.30	61.44	60.61	61.64	61.05	60.47	4.17	3.08
P+Mj	L	594.98	585.29	579.94	577.31	588.26	585.42	582.60	30.82	22.74	78.56	77.71	77.35	76.99	78.47	78.08	77.71	4.31	3.18
	U	527.79	514.13	511.79	507.16	519.21	516.71	514.24	26.67	19.68	61.74	61.00	60.45	59.90	61.61	61.32	61.02	4.34	3.20
P+Rh+Mj	L	636.64	620.41	611.94	606.17	605.91	601.81	597.17	35.92	36.51	82.49	81.59	80.83	80.07	80.43	79.65	79.26	4.68	3.45
	U	575.29	550.12	545.06	537.61	539.98	534.80	532.24	29.88	22.05	66.14	64.66	63.77	62.90	64.07	63.46	65.15	4.46	3.29
L.S.D.																			
0.01	L	46.47	40.18	42.62	38.95	33.10	28.07	32.64			7.45	6.67	6.49	6.86	4.72	4.87	4.62		
	U	54.10	43.44	45.40	41.95	35.61	37.62	34.56			4.73	4.28	4.43	4.47	4.01	4.12	4.02		
0.05	L	34.07	29.46	31.25	28.56	24.27	20.58	23.93			5.46	4.89	4.76	5.03	3.46	3.57	3.39		
	U	29.67	21.85	33.29	30.76	26.11	27.58	25.34			3.47	3.14	3.25	3.28	2.94	3.02	2.95		

L = Lower surface, U = Upper surface

Each value is mean of five replicates.

Table 18. Interactive effects of simulated acid rain, root-knot nematodes and root nodule bacteria on number and length of trichomes on leaves of lentil.

Treatment		Number of trichomes/cm^2								Length of trichomes (μm^2)							
		pH 5			pH 3.2			L.S.D.		pH 5				pH 3.2			L.S.D.	
		C	Pe	S	Pt	Pe	S	Pt	0.01	0.05	C	Pe	S	Pt	Pe	S	Pt	0.01	0.05
P (Control)	L	2591.84	2721.43	2721.28	2720.30	2928.78	2928.81	2927.45	102.42	75.58	733.17	766.16	766.24	765.35	799.16	799.35	798.02	42.81	31.59
	U	1548.53	1641.44	1641.38	1641.25	1780.81	1779.24	1773.68	80.84	59.43	680.16	717.57	717.38	716.15	748.18	748.25	747.39	32.96	24.32
P+Rh	L	1963.52	2126.12	2125.81	2125.78	2482.02	2481.68	2481.65	79.03	59.32	591.26	636.47	637.59	637.21	726.50	725.84	725.35	47.10	34.76
	U	1082.87	1224.96	1224.62	1224.33	1459.68	1459.32	1459.60	40.22	29.68	507.58	565.01	563.92	564.83	656.29	656.16	655.79	39.58	29.21
P+Mi	L	2901.94	2952.75	2979.97	2993.58	3075.22	3089.86	3104.51	110.80	82.76	784.59	804.47	808.30	812.13	823.13	827.23	831.12	40.07	29.57
	U	1773.05	1822.00	1838.41	1854.83	1878.75	1887.66	1905.47	99.26	73.25	741.37	767.89	771.39	774.97	774.36	778.10	781.84	41.25	30.44
P+Rh+Mi	L	2545.63	2636.39	2684.66	2721.43	2874.04	2914.96	2951.05	103.82	76.61	694.23	718.28	728.20	738.30	776.54	784.01	791.54	39.07	28.83
	U	1453.42	1518.33	1557.98	1585.32	1707.96	1747.83	1780.81	72.42	53.44	633.65	661.90	670.77	685.82	717.00	727.20	737.59	47.04	34.71
P+Mj	L	2825.11	2884.72	2898.33	2911.92	2987.35	3002.04	3016.65	107.53	79.35	762.50	785.32	787.62	789.15	817.15	811.04	815.14	44.52	32.95
	U	1718.87	1780.96	1789.17	1805.59	1834.23	1843.14	1852.04	110.46	81.51	716.25	746.27	759.86	753.45	760.89	763.14	766.88	38.45	28.37
P+Rh+Mj	L	2242.15	2326.39	2375.68	2426.61	2667.28	2729.09	2793.19	100.66	74.28	630.17	659.93	667.47	647.49	740.50	751.06	758.27	41.45	30.59
	U	1282.74	1359.51	1386.95	1421.72	1608.98	1645.66	1683.67	86.66	63.95	552.56	552.28	604.73	617.58	679.37	693.76	703.56	39.01	28.79
L.S.D.																			
0.01	L	172.99	160.83	157.81	160.23	139.97	152.14	149.78			56.04	49.88	51.31	54.34	37.64	34.83	36.50		
	U	169.49	156.63	153.16	162.79	129.93	131.86	128.54			40.11	33.85	35.83	35.94	27.86	28.98	26.79		
0.05	L	126.84	117.92	115.71	117.48	102.63	11.55	109.82			41.09	36.57	37.62	39.84	27.60	25.54	26.76		
	U	124.27	114.84	112.30	119.36	95.27	96.68	94.25			29.41	24.82	26.27	26.35	20.43	21.25	19.64		

L = Lower surface, U = Upper surface.

Each value is mean of five replicates.

DISCUSSION

The seed germination of chick-pea and lentil was inhibited in the acidic media. During the seed germination, several biochemical changes occur. (Paleg, 1960a, 1960b; Yomo, 1960a, 1960b). α-amylase, produced in the outer layers of germinating seeds plays important role in the germination of seeds, by converting the reserved carbohydrates into utilizable forms (Yomo, 1958). The enzyme α-amylase is sensitive to pH of both acidic and alkaline range, because in these pH ranges enzymes are denatured (Fruton and Simmonds, 1959; Devlin, 1975). It is likely that the poor germination of seeds of chick-pea and lentil resulted from the diminished activity of α-amylase, since in the soil, acidified water was added. This relationship was also evident from the fact that a stepwise decrease in germination occurred with increasing acidity. Besides it, the toxic effects of sulphate ions might have adversely affected the physiological and biochemical activities of seeds during the germination. Tamm and Cowling (1976) has found the inhibition of seed germination by acidified rain. The difference in the reduction of seed germination of chick-pea and lentil caused by the same pH levels may be due to the difference in the nature of the seed coats, which would interfere in the permeability of water (Hyde, 1954). The greater post-emergence mortality of seedlings in lentil than chick-

pea may be also related to their differential response to acidity derived from their inherent characters.

The pH levels variously affected the growth of Rhizobium in vitro. The chick-pea strain of Rhizobium belongs to the slow growing Rhizobium of cowpea group while the lentil strain of Rhizobium belongs to R. leguminosarum, the fast growing group (Burton, 1979; Elkan, 1984). Slow growing bacteria are non-acid producing and increase the pH of media, while the fast growing bacteria produce acids (Vincent, 1977). Thus the slow growing bacteria would be susceptible to acidity while the fast growing bacteria would be less affected by the pH in acidic range. In the present study at pH 6, growth of chick-pea strain of Rhizobium was not affected, while the lentil strain of Rhizobium showed a slight increase in growth. The fast growing lentil strain, which is acid producing was favoured by the slight acidity while the chick-pea strain, a non-acid producer remained unaffected at pH 6 . But with further increase in the acidity, growth of both the strains was inhibited. At pH 3.2, growth of chick-pea strain of Rhizobium was totally inhibited, but the lentil strain showed slight growth. The growth of lentil strain was completely inhibited at pH 2.5. At all the pH levels, the extent of growth of chick-pea strain was greater than lentil strain. This variations may be related to their relative affinity

towards acidity. The sulphate ion might have also contributed towards the growth inhibition of Rhizobium strains.

Juvenile hatching of both M. incognita and M. javanica was inhibited by pH in acid range and gradually decreased with the increasing acidity. The juvenile hatching of root-knot nematodes is known to be affected by the pH level. The optimum pH for the hatching is 7 and inhibition occurs at pH levels lower than 7 (Ahmad and Khan, 1964; Wallace, 1966).

The adverse effects of simulated acid rains on plant growth and yield characters, leaf chlorophyll and seed protein contents were directly correlated with pH level of the rain.The rain of lower pH level (pH 3.2) was more inhibitory than rain of comparatively higher pH level (pH 5). The reports available in literature show that reduction in growth of crop plants generally occurs when the plants are exposed to acidified rain (Shriner and Johnston, 1981; Brewer and Heagle, 1983; Ashenden and Bell, 1987; Evans, 1988). The yield losses in crop plants have also been observed (Shriner and Johnston, 1981; Brewer and Heagle, 1983; Ashenden and Bell, 1987 Porter et al., 1987; Pell and Puente, 1987; Hua and Wang, 1987). The reduction in plant growth might have been caused by the reduced photosynthesis and other physiological activities. The reduction in the yield may be related to reduced plant growth and flowering and

failure of fruit setting due to failure of pollen germination (Wertheim and Craker, 1987, 1988). The low pH levels of acid rains or sulphate ions present in the rains might be directly responsible for reduced plant growth. According to Waldron (1978), the pH level is more responsible for the reduction in growth and yield than the sulphate ions. Shriner and Johnston (1981) have also concluded that pH level was mainly responsible for growth reductions of soybean caused by acid rain. The chlorophyll content of the leaves in both chick-pea and lentil decreased with the increasing acidity. The phaeophytinization of chlorophyll molecules caused by sulphate ions and by low pH (Rao and LeBlanc, 1966; Sharma and Rao, 1985), may be claimed to be responsible for low chlorophyll content of leaves treated with acid rains. The reduction in protein content might have been caused through the overall poor growth of the acid rain exposed plants. In earlier studies, the seed protein content in soybean have been found to be reduced by acidic rainfalls (Evans et al. 1981, 1983). The reduction in the number of stomata, size of stomata and stomatal aperture, number and length of trichome-hydathodes and the increase in the number and length of trichomes in the simulated acid rain exposed plants were apparently adaptations of the plants to check excessive transpiration induced by the acid rains. Increase in the measures of trichomes support the above contention.

The simulated acid rains suppressed root nodulation on chick-pea and lentil. The number of functional nodules was also reduced. In some earlier studies similar effects of acid rain on root nodulation by Rhizobium have been recognised (Shriner, 1978; Waldron, 1978; Shriner and Johnston, 1981; Brewer and Heagle, 1983). The reduction in the nodulation was directly correlated with the pH level. The direct inhibitory effect of low pH on Rhizobium and poor plant growth under acid rain stresses can be called as possible factors responsible for inhibition. Some studies have also shown that low pH levels were inhibitory for Rhizobium growth (Alexander, 1984; Freire, 1984; Munns.et al.,1979). The direct toxicity of H^+ or SO_4^{--} ions present in the rains acidified with sulphuric acid may be attributed as primary factor for such suppression. Additionally, the greater solubility of pH dependent toxic metals like Mn (Waldron, 1978) might also effect root nodulation and plant growth. In the plants inoculated with Rhizobium, the suppression of root nodulation might have reduced the nitrogenase activity (Shriner and Johnston, 1981). These effects might have acted as contributory factors for the reduction in plant growth and yield, in addition to direct effects of acid rains on plants altering their physiological and biochemical processes.

The gall formation and eggmass production of both

M. incognita and M. javanica were considerably reduced in the acid rain exposed plants of chick-pea and lentil. The effect of acid rain on root-knot nematodes has gained negligible study. The decreased root infection and reproduction of M. hapla in red kidney beans under the stress of acid rain was demonstrated by Shriner (1978). Most recently Bolla and Fitzsimmons (1988) found that reproduction of Bursaphelenchus xylophilus was decreased in pine seedlings treated with acid rain. The present observations are in accordance to these observations. In the various acid rain treatments, gall formation and eggmass production by the root-knot nematodes were lowest in the plants where nematode inoculation followed the acid rain exposure (pre-inoculation treatment) and were highest in the plants where acid rain exposure followed the nematode inoculation (post-inoculation treatment). This differences in the gall formation and eggmass production indicated the alterations in the host physiology which make plants tolerant to nematode infection as well as to other pathogens (Evans, 1982; Haines, et al., 1985; Bolla and Fitzsimmons, 1988). The effect of nematodes due to the difference in the pathogenicity in all the three exposures of acid rain in relation to nematode inoculation varied according to the nematode infection on the various parameters as well as on the interaction of the root-knot nematodes with Rhizobium.

Interaction between simulated acid rain (pH 3.2, 5) and Rhizobium was antagonistic on both the crops. Root-nodulation was inhibited and consequently the plants under acid rain stress could derive less benefit through nodulation. Interaction between acid rain and root-knot nematodes was also antagonistic, interacting under the acid rain stress both species of root-knot nematodes were inhibited. As in other experiments Rhizobium and root-knot nematodes interacted antagonistically and the interactive effects were evident on the parameters considered for study. When all the three, simulated acid rain, Rhizobium and root-knot nematode (either species) were together, the interaction was antagonistic and both the living components, Rhizobium and Meloidogyne sp. were suppressed. Plant under the influence of this three dimensionally interacting system showed some improvement in comparison to the plants having single stress (acid rain or root-knot nematode) in relation to plant growth and yield and other considered parameters. The adverse effect was greatest when either species of Meloidogyne interacted with simulated acid rain.

SUMMARY

Seed germination of chick-pea and lentil was suppressed and post-emergence mortality of seedlings was increased

by the soil acidity. Inhibition of seed germination and post-emergence mortality of seedlings were found to be pH dependent. In relation to germination, lentil seeds were more tolerant to acidity than chick-pea seeds. But the seedlings of lentil were more sensitive to acidity, and suffered greater mortality than chick-pea seedlings.

Growth of chick-pea and lentil strains of Rhizobium was inhibited by the pH of the media. The extent of inhibition was correlated with the acidity of the medium. But at pH 6, growth of chick-pea strain of Rhizobium was unaffected while lentil strain of Rhizobium showed slightly better growth than control. Total inhibition of growth of chick-pea strain was recorded at pH 3.2 while total inhibition in growth of lentil strain was found at pH 2.5. The chick-pea strain of Rhizobium was apparently more sensitive to acidity than lentil strain.

Juvenile hatching of M. incognita and M. javanica was adversely affected by the acidity of the media and decreased with the increasing acidity. The suppression in juvenile hatching of M. incognita was greater than M. javanica at pH 6 but from pH 5 onward in acidic range the suppression in juvenile hatching of M. javanica was more than M. incognita.

Simulated acid rains of pH 5 and 3.2 adversely

affected plant growth (length, fresh and dry weights of shoot and root), flowering, fruiting, chlorophyll content of leaves and protein content of seeds of chick-pea and lentil. The adverse effect of the acid rain of pH 3.2 was consistently greater on all the considered parameters than pH 5. The simulated acid rains also suppressed the favourable effects of Rhizobium and deleterious effects of the species of Meloidogyne. The combined effects of Rhizobium and either species of Meloidogyne were also adversely affected by the acid rains. These parameters were highest in pre-inoculation treatment and lowest in post-inoculation treatment of simulated acid rains (pH 3.2 and 5) in relation to nematode inoculation.

Root-galling and eggmass production of M. incognita and M. javanica were suppressed by the acid rains. The suppressing effect of Rhizobium on root galling and eggmass production of both the species of Meloidogyne was adversely affected by the acid rains. On both the crops, root nodulation of Rhizobium was also adversely affected. The suppression of root nodulation and infection of nodules by the root-knot nematodes were reduced by the acid rains. Root galling and eggmass production were greatest in post-inoculation treatment and lowest in pre-inoculation treatments of the acid rains, while the root nodulation (number of total, functional and infected nodules) was highest in pre-inoculation treatment and lowest in post-inoculation treatment.

Leaf epidermal characters responded variously to the simulated acid rains. The simulated acid rains reduced the number of stomata, size of stomata and stomatal aperture and the number and length of trichome-hydathodes. The number and length of trichome were increased. All these effects were consistently greater with acid rain of pH 3.2 than pH 5.

The effects of Rhizobium and either species of Meloidogyne, separately and in combination were suppressed by the acid rains. The number of stomata, size of stomata and stomatal aperture and number and length of trichome-hydathodes were greatest in pre-inoculation treatment and lowest in post-inoculation treatment of the acid rains (pH 3.2 and 5). The number and length of trichomes were greatest in post-inoculation treatment and lowest in pre-inoculation treatment of the acid rains.

SECTION V

INTERACTION OF AMBIENT FLYASH POLLUTED SOIL/FLYASH AMENDED SOIL, ROOT-KNOT NEMATODES AND ROOT NODULE BACTERIA ON CHICK-PEA AND LENTIL

The Thermal Power Plant, Kasimpur, the pollution source in the study, emits flyash which spreads in the nearby areas and alters the soil quality depending on the extent of deposition. The effects of the soil containing flyash, on seed germination of chick-pea and lentil, and on juvenile hatching of Meloidogyne incognita and M. javanica, and interaction of flyash polluted soils, root-knot nematodes and root nodule bacteria and their interactive effects on chick-pea and lentil were studied in glasshouse conditions in two ways. They are presented as part A and part B separately, in this section. In part A study, ambient flyash polluted soils were used and in part B study, field soil was amended artificially with flyash.

For part A of the study, the ambient flyash polluted soils were collected from two different sites, 1/2 km and 2 km away from the thermal power plant, which were also the sites for conducting experiments in ambient air. Physical and chemical characteristics of the soils were also examined.

For part B, field soil was amended by adding flyash to achieve different levels of flyash (v/v) i.e. 0 (control),

10, 20, 30, 40, 50, 60, 70, 80, 90 and 100%. Flyash for amendment of the soil was obtained directly from the Thermal Power Plant, Kasimpur.

MATERIALS AND METHODS

Physical and chemical properties of soil

In order to assess the effect of air pollution on the characteristics of soils, soil samples were collected by soil auger from surface to 1 feet depth from 2 different sites, in the polluted area 1/2 (S_1) and 2 km (S_2) away from the thermal power plant and from the unpolluted area. The samples consisted of five sub-samples collected at random. The soil samples properly marked and packed in polythene bags were brought to laboratory and their physical characteristics like soil texture, porosity, water holding capacity and chemical properties like pH, conductivity, organic matter, cation exchange capacity, carbonates, bicarbonates and sulphates were determined employing standard methods (Jackson, 1958; Chopra and Kanwar, 1976).

Seed germination

To assess the impact of the ambient flyash polluted soil on the seed germination of the crops, healthy seeds of chick-pea (cv. T-3) and lentil (cv. T-36) were sown in flyash polluted soils and in unpolluted soil, sterilized

and filled in 30 cm clay pots (100 seeds/pot). Each treatment was replicated 5 times. After seven days, the successfully germinated seeds and the seeds which germinated but seedlings died after emergence (post-emergence mortality) were counted. In the same way, the seed germination and post-emergence mortality of seedlings were determined in the various artificially flyash amended soils and per cent reduction in relation to control was calculated.

Juvenile hatching

For studying the effect of ambient flyash polluted soil and artificially flyash amended soil on juvenile hatching of M. incognita and M. javanica, 50 eggmasses of almost equal size of each species were kept separately in the polluted as well as in unpolluted soil in 7 cm icecream cups and moistened. Each set was replicated five times. The cups were kept moist during the sudy. After seven days, the hatched juveniles (J_2) were isolated and collected over 500 mesh sieve and counted under the binocular light micro-scope and juvenile hatching/eggmass was determined and per cent reduction over control was calculated.

Interaction studies

To examine the interaction of ambient flyash polluted soil /artificially flyash amended soil, root-knot nematodes and root nodule bacteria and their interactive affects on

chick-pea and lentil in glasshouse, seeds of both crops were sown in sterilized soils (polluted and unpolluted), in 30 cm clay pots and the root nodule bacteria and root-knot nematodes treatments were given as done in the section II. Each treatment was replicated five times. At the termination (100 days after sowing) of the experiments, various parameters of study as given in the section II were considered.

RESULTS

Part A - AMBIENT FLYASH POLLUTED SOIL

Physico-chemical characteristics of the ambient polluted soils

The physico-chemical characteristics of the soils collected from the two different sites (S_1 and S_2) in the vicinity of the Thermal Power Plant, Kasimpur and from the University Farm, Aligarh (unpolluted site) are summarized in Table 1. In general, soil porosity, water holding capacity, conductivity, cation exchange capacity and organic matter, sulphate, carbonate and bicarbonate contents of soils collected from both polluted sites were greater than of the soil from the unpolluted site. These values in most cases were greater in S_1 soil than in S_2 soil. The porosity of the soil from the S_1 site was higher than soil of the unpolluted site. The porosity of S_1 soil was 54.28% in comparison to 43.24% of the soil from the unpolluted site. The porosity

of S_2 soil was also slightly greater than of unpolluted site. The water holding capacity of the soil from S_1 was 50.22% as compared to 35.49% of the soil of unpolluted

Table 1. Physico-chemical characteristics of the soil from the unpolluted site and the soils collected from the polluted sites (1/2 km and 2 km distance) in the vicinity of the Thermal Power Plant, Kasimpur.

Soil characteristics	Unpolluted site	Polluted sites	
		S_1 (1/2 km)	S_2 (2 Km)
Physical			
Sand %	77.00	74.25	69.50
Silt %	14.50	20.50	21.50
Clay %	8.50	5.25	13.25
Soil texture class	loamy sand	sandy loam	sandy loam
Porosity %	43.24	54.28	44.86
Water holding capacity %	35.49	50.22	34.23
Chemical			
pH	7.7	6.8	7.1
Conductivity (mhos/cm)	3.33×10^{-3}	5.66×10^{-3}	4.30×10^{-3}
Cation exchange capacity (me) %	4.1	15.8	14.3
Organic matter %	2.28	9.59	4.10
Sulphate %	3.16	5.72	5.31
Carbonate %	0.102	0.120	0.120
Bicarbonate %	0.441	0.854	0.610

site. The porosity of soil from S_2 was, however, 34.23%. Based on the proportions of soil particles, the soils of

the polluted sites were designated as sandyloam whereas the soil of the unpolluted site was categorized as loamy sand. The soil of the unpolluted site was in alkaline range while the S_1 soil was in acidic range. The soil from S_2 was almost neutral.

The conductivity was also greater in the soils obtained from the polluted sites. It was 5.66×10^{-3} mhos/cm at S_1 and 4.30×10^{-3} mhos/cm at S_2. The cation exchange capacity considerably higher in the soils from the polluted sites. It was 15.8 me at S_1 and 14.3 me at S_2.

The organic matter content of the soils, from polluted sites was greater than of the soil from the unpolluted site. It was 9.59% at S_1 and 4.10% at S_2 in contrast to 2.28% of the soil from the unpolluted site. The carbonates and bicarbonates were greater in soil from polluted sites than in the soil of unpolluted site. Bicarbonate content of soil from S_1 was much greater than of soil from S_2.

Seed germination

Seed germination of both chick-pea and lentil was inhibited in soils collected from the polluted sites (S_1 and S_2). The reduction in seed germination was greater in the soil from S_1 than S_2 and the percent reduction in seed germination of chick-pea was 21.3 and 12.3 and of lentil 19.8 and 10.5 in the soils from S_1 and S_2 respectively. The soils from the polluted sites, in this respect were

more inhibitory for chick-pea than lentil. The seedlings mortality after emergence was also greater in the soil from

Table 2. Seed germination of chick-pea and lentil in the soils from the polluted sites and unpolluted site.

Soil	Chick-pea			Lentil		
	Germination %	Reduction over control %	Seedling mortality	Germination %	Reduction over control %	Seedling mortality %
Unpolluted site(control)	90	-	2	86	-	4
Polluted sites S_1(1/2 km)	71	21.3	12	69	19.8	14
S_2 (2 km)	79	12.3	7	77	10.5	8

the polluted sites. The effect was more in S_1 soil. The mortality of seedlings after emergence was greater in lentil than chick-pea (Table 2).

Juvenile hatching

The juvenile hatching of M. incognita and M. javanica was suppressed in the soils from the polluted sites.This suppressive effect was greater in the S_1 soil than S_2 soil and was also greater for M. incognita than M. javanica. The

Table 3. Hatching of juveniles (J_2) of Meloidogyne incognita and Meloidogyne javanica in the soils from the polluted sites and the unpolluted site.

Soil	M. incognita		M. javanica	
	Juveniles/ eggmass	Reducation over control (%)	Juveniles/ eggmass	Reduction over control (%)
Unpolluted site (control)	269		256	
Polluted sites				
S_1 (1/2 km)	124	53.90	129	49.61
S_2 (2 km)	217	19.33	212	17.19

per cent reduction in hatching of the juveniles of M. incognita was 53.90 and 19.33 and of M. javanica 49.61 and 17.19 in S_1 and S_2 soils respectively (Table 3).

CHICK-PEA, Cicer arietinum L.

Plant growth and yield

Flyash polluted soil significantly promoted the plant growth of chick-pea (Table 4). The plant growth parameters (lengths, fresh and dry weights of shoot and root) increased in the polluted soils. Greater increase occurred in S_1 soil than S_2 soil. The addition of Rhizobium increased the plant growth parameters in the unpolluted soil. The increase in

Table 4. Interactive effects of ambient flyash polluted soil, root-knot nematodes and root nodule bacteria on plant growth and yield characters of chick-pea.

Treatment		Length (cm)			L.S.D.		Fresh weight (g)			L.S.D.		Dry weight (g)			L.S.D.		Flower/Fruit				L.S.D.	
		C	S_1	S_2	0.01	0.05	C	S_1	S_2	0.01	0.05	C	S_1	S_2	0.01	0.05		C	S_1	S_2	0.01	0.05
P (control)	S	32.6	44.6	38.6	3.16	2.17	25.25	36.25	29.95	3.08	2.12	5.80	8.15	6.75	0.67	0.46	FL	96.8	146.2	117.4	8.47	5.82
	R	22.7	28.2	24.2	1.66	1.14	17.50	23.15	19.45	1.51	1.04	4.15	6.30	4.85	0.89	0.61	FR	64.6	115.2	87.2	6.17	4.24
P+Rh	S	42.4	50.7	45.3	3.61	2.48	38.55	48.85	42.50	3.59	2.47	8.95	10.85	9.45	0.60	0.41	FL	150.4	172.4	159.6	7.51	5.16
	R	27.5	32.5	29.1	2.15	1.48	24.25	28.00	24.85	1.10	1.17	5.75	7.60	6.35	0.90	0.62	FR	110.2	132.4	114.2	4.79	3.29
P+Mi	S	25.2	39.2	30.5	1.83	1.26	21.85	33.65	26.75	3.75	2.58	5.10	7.60	6.10	0.86	0.59	FL	58.8	108.2	78.2	7.23	4.97
	R	16.4	24.9	20.5	2.27	1.56	14.80	21.50	16.75	1.76	1.21	3.45	5.70	4.35	0.79	0.54	FR	35.8	80.0	52.6	6.36	4.37
P+Rh+Mi	S	30.7	42.7	35.3	3.19	2.19	30.40	40.75	34.50	3.45	2.37	7.20	9.50	8.40	0.90	0.62	FL	70.2	120.4	92.4	8.99	6.18
	R	19.6	27.0	22.9	2.72	1.87	18.30	23.95	19.80	1.59	1.09	4.00	6.20	4.75	0.99	0.68	FR	45.4	88.6	63.2	5.15	3.54
P+Mj	S	29.3	42.4	34.9	3.03	2.08	24.15	35.20	28.65	3.80	2.61	5.45	8.00	6.50	1.00	0.69	FL	70.4	119.8	91.6	9.27	6.36
	R	19.8	26.6	22.4	2.33	1.60	16.75	22.70	18.80	1.60	1.10	3.85	6.10	4.60	0.74	0.51	FR	48.0	100.2	69.8	6.21	4.27
P+Rh+Mj	S	36.4	47.6	40.8	3.36	2.31	34.15	46.25	40.55	4.09	2.81	8.15	10.45	9.15	1.03	0.71	FL	98.2	147.6	119.4	8.61	5.92
	R	23.9	29.8	26.2	2.23	1.53	21.85	26.45	23.15	1.88	1.29	4.90	7.30	5.65	0.64	0.44	FR	67.2	116.8	89.6	5.99	4.12
L.S.D.																						
0.01	S	3.72	4.28	3.91			2.03	2.82	2.65			0.94	0.72	1.01			FL	6.30	7.05	8.24		
	R	1.73	1.99	1.73			1.55	1.40	1.58			0.63	0.79	0.67			FR	5.40	10.01	8.56		
0.05	S	2.73	3.14	2.87			1.49	2.07	1.94			0.69	0.53	0.74			FL	4.62	5.17	6.04		
	R	1.27	1.46	1.27			1.14	1.03	1.16			0.46	0.58	0.49			FR	3.96	7.34	6.28		

S = Shoot, R = Root FL = Flower, FR = Fruit

Each value is mean of five replicates.

P = Plant; Rh = *Rhizobium*, Mi = *Meloidogyne incognita*, Mj = *M. javanica*, C = Control soil, S_1 = 1/2 km soil, S_2 = 2 km soil.

These abbreviations are common to all the subsequent tables in the section V A.

the growth parameters in the polluted soils was comparatively smaller than in the unpolluted soil. M. incognita retarded the plant growth and reduced the length, fresh and dry weights of shoot and root. The reductions were greater in the unpolluted soil than in the polluted soils. Along with Rhizobium, M. incognita caused less reduction in the growth parameters in all the three soils. M. javanica also reduced the growth parameters. Reduction in shoot length was significant at $P = 0.05$. But reductions in shoot and root weights were not significant. When M. javanica and Rhizobium were together, plant growth (length, fresh and dry weights of shoot and root) was greater than in check (plant alone) or than in M. javanica inoculated plants. The increases in growth parameters were more in the unpolluted soil than in the polluted soils in comparison to their respective checks (Table 4, Fig. 1A).

The pollution of soil by flyash also affected the yield parameters (number of flowers and fruits) of chick-pea. Plants grown in the polluted soils showed greater flowering and fruiting than those in unpolluted soil. Rhizobium also increased flowering and fruiting both in polluted and unpolluted soils. When compared to respective checks, increase in the unpolluted soil was, however, greater. Inoculation with M. incognita reduced the yield parameters. In the presence of Rhizobium, this reduction was comparatively less. The reductions caused by M. incognita in the presence or

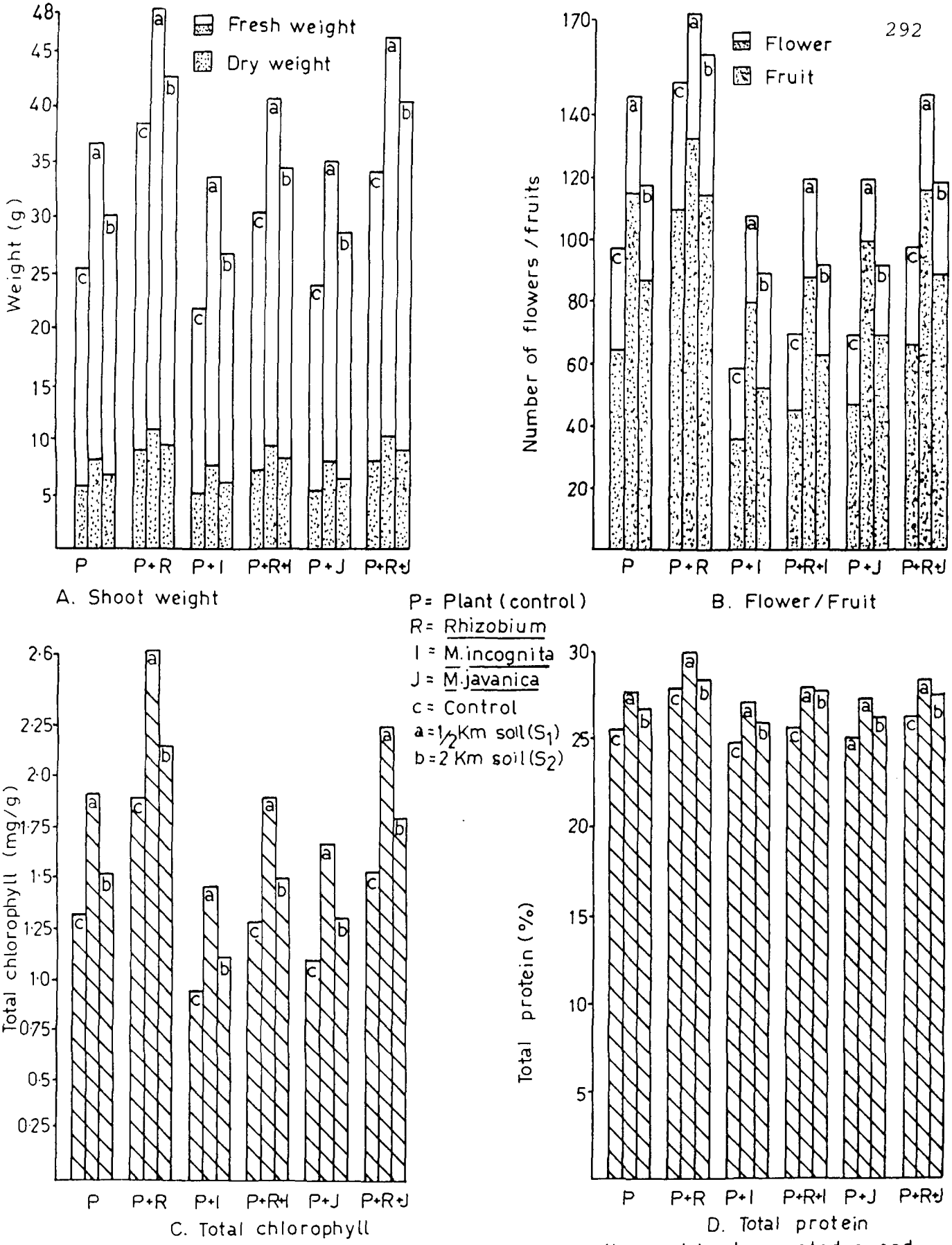

Fig. 1. Interactive effects of ambient flyash polluted soil, root-knot nematodes and root nodule bacteria on some parameters of chick-pea.

absence of Rhizobium were greater in the unpolluted soil than the polluted soils (Table 4, Fig. 1 B)

M. javanica also reduced the flowering and fruiting. M. javanica in the presence of Rhizobium, also caused relatively less reduction, both in polluted or in unpolluted soils. These differences were, however, not significant (Table 4, Fig. 1B).

Root-knot disease and root nodulation

M. incognita and M. javanica induced root galling and produced eggmasses on chick-pea. M. incognita was more pathogenic at the inoculum level used (1000 J_2) than M. javanica, because gall formation and eggmass production were greater in M. incognita inoculated plants. Flyash polluted soil significantly affected the root galling and eggmass production. In general root galling was favoured and eggmass production was inhibited in polluted soils of both the sites. Enhancement of galling and inhibition of eggmasses were greater in polluted soil from S_1 than S_2. This trend in effects of flyash polluted soil was same for M. incognita and M. javanica. Presence of Rhizobium adversely affected the root galling and eggmass production of both the species (Table 5).

Root nodulation (number of nodules/root system) was significantly suppressed in polluted soils (Table 5). This

Table 5. Interactive effects of ambient flyash polluted soil, root-knot nematodes and root nodule bacteria on root-galling, eggmass production, bacterial nodulation, leaf chlorophyll content& protein content of seeds of chick-pea.

Treatment	Gall/Eggmass					Nodule					Chlorophyll (mg/g)					Protein(%)				
		C	S_1	S_2	L.S.D. 0.01	L.S.D. 0.05		C	S_1	S_2	L.S.D. 0.01	L.S.D. 0.05		C	S_1	S_2	L.S.D. 0.01	L.S.D. 0.05		C	S_1	S_2	L.S.D. 0.01	L.S.D. 0.05
P (Control)													A	0.621	1.029	0.829	0.090	0.062	S	11.30	11.42	11.32	1.13	0.78
													B	0.571	0.830	0.650	0.076	0.052	I	14.36	16.28	15.42	1.29	0.89
													T	1.313	1.905	1.519	0.138	0.095	T	25.66	27.70	26.74	1.50	1.03
P+Rh							T	140.4	75.0	121.4	20.02	13.76	A	0.943	1.411	1.166	0.074	0.051	S	12.34	12.04	12.10	0.77	0.53
							F	120.6	57.6	96.4	13.79	9.48	B	0.878	1.132	0.917	0.071	0.049	I	15.62	16.92	16.24	0.68	0.47
													T	1.901	2.609	2.142	0.093	0.064	T	27.96	29.96	28.34	1.18	0.81
P+Mi	G	176.2	215.2	190.4	9.15	6.29							A	0.447	0.789	0.606	0.074	0.051	S	10.94	11.18	11.04	0.93	0.64
	E	108.6	29.6	64.6	6.95	4.78							B	0.412	0.633	0.479	0.071	0.049	I	13.96	15.98	14.96	0.89	0.61
													T	0.945	1.454	1.113	0.121	0.083	T	24.90	27.16	26.00	1.79	1.23
P+Rh+Mi	G	125.6	172.4	143.4	7.91	5.44	T	100.2	61.4	85.2	11.12	7.64	A	0.612	1.024	0.812	0.070	0.048	S	11.40	11.58	11.50	1.00	0.68
	E	86.4	24.2	55.8	6.68	4.59	F	70.8	37.2	56.8	11.33	7.79	B	0.559	0.817	0.641	0.064	0.044	I	14.38	16.38	15.36	0.93	0.64
							I	15.2	26.8	20.2	2.81	1.93	T	1.285	1.890	1.491	0.141	0.097	T	25.78	27.96	27.86	1.32	0.91
P+Mj	G	83.4	110.6	97.6	5.73	3.94							A	0.520	0.911	0.706	0.092	0.063	S	11.10	11.28	11.12	1.03	0.71
	E	48.6	21.4	34.6	4.79	3.29							B	0.479	0.725	0.556	0.061	0.042	I	14.06	16.14	15.16	0.99	0.68
													T	1.094	1.671	1.298	0.173	0.119	T	25.16	27.42	26.28	1.43	0.98
P+Rh+Mj	G	52.2	78.6	63.8	5.06	3.48	T	125.4	74.6	110.8	10.90	7.49	A	0.729	1.210	0.979	0.079	0.048	S	11.68	11.82	11.76	1.00	0.69
	E	33.8	17.4	29.2	4.71	3.24	F	100.6	50.8	81.0	9.94	6.83	B	0.660	0.973	0.764	0.083	0.057	I	14.72	16.68	15.84	0.92	0.63
							I	11.2	20.2	15.1	2.72	1.87	T	1.529	2.239	1.789	0.144	0.099	T	26.40	28.50	27.60	1.27	0.87
L.S.D.																								
0.01	G	8.05	16.08	13.78			T	18.46	7.32	10.01			A	0.060	0.065	0.070			S	0.65	0.70	0.78		
	E	7.40	0.87	3.04			F	13.30	6.24	9.27			B	0.057	0.071	0.045			I	0.63	0.75	0.86		
							I	3.17	4.03	3.48			T	0.106	0.115	0.080			T	0.97	1.04	1.10		
0.05	G	5.74	11.45	9.83			T	12.96	5.03	6.88			A	0.044	0.048	0.051			S	0.48	0.51	0.57		
	E	5.28	0.62	2.17			F	9.14	4.29	6.37			B	0.042	0.052	0.033			I	0.46	0.55	0.63		
							I	1.91	2.43	2.10			T	0.078	0.084	0.073			T	0.71	0.76	0.81		

G = Gall, E = Eggmass

T = Total, F = Functional, I = Infected

A = Chl.a, B = Chl.b, T = Total chl.

S = Soluble, I = Insoluble, T = Total

Each value is mean of five replicates.

effect was greater in S_1 soil than S_2 soil. The number of functional and total nodules were suppressed in the polluted soils. In S_2 soil, the suppression in the number of total nodules was significant only at P = 0.05. M. incognita and M. javanica both suppressed root nodulation. M. incognita was relatively more suppressive. Flyash polluted soils and nematode infections by both species, separately decreased the number of functional nodules. The suppression in nodulation due to root-knot nematodes was greater in unpolluted soil than in polluted soils when compared with their respective checks. The nodules were also found infected with root-knot nematodes. M. incognita caused greater infection of nodules than M. javanica. Number of root-knot nematode infected nodules, was greater in polluted soils (Table 5).

Leaf pigments and seed proteins

Leaf pigments (chlorophyll a, chlorophyll b and total chlorophyll) and protein content (soluble and insoluble proteins) of seeds of plants grown in polluted soils were greater than plants grown in unpolluted soil. The increase in chlorophyll content was significant. Chlorophyll content was enhanced by inoculation with Rhizobium. This increase was greater in unpolluted soil than polluted soils when compared with their respective checks. Both M. incognita and M. javanica reduced the chlorophyll content and reduction was greater in unpolluted soil than polluted soils.

When M. incognita was together with Rhizobium, the reduction in chlorophyll content was smaller and was not significant. But M. javanica along with Rhizobium significantly increased the chlorophyll content. The changes in chlorophyll content due to the combined infections of root-knot nematodes and Rhizobium were greater in unpolluted soil than polluted soils (Table 5, Fig. 1C).

Plants grown in flyash polluted soils contained more soluble and insoluble proteins in their seeds than plants grown in unpolluted soil (Table 5). This increase was greater in the S_1 soil than S_2 soil. The increase in soluble protein in S_2 soil was not significant while the increase in insoluble and total protein contents was significant at $P = 0.05$. Protein content was increased by Rhizobium inoculation. The increase was greater in unpolluted soil than polluted soils. M. incognita reduced the protein content while M. javanica did not cause significant reduction. The reduction in protein content by root-knot nematodes were smaller in polluted soils than unpolluted soil. Protein content of seeds in plants inoculated with Rhizobium and either species of root-knot nematodes were greater than in plants inoculated with the nematode alone. This difference was, however, not significant. The increase in protein content with the addition of Rhizobium in nematode inoculated plants was smaller in polluted soils than unpolluted soil (Table 5, Fig. 1D).

Leaf epidermal characters

The different leaf epidermal characters considered in the study were affected by root-knot nematodes, Rhizobium and flyash polluted soil (Table 6). The number of stomata and trichome-hydathodes, size of stomata and stomatal aperture and the length of trichome-hydathodes were increased in the polluted soils. Effect of polluted soil from S_1 in these respects was greater than S_2. Increase in the measurements of stomata and stomatal aperture and trichome-hydathodes on lower surface in S_2 soil was not significant. The increase of stomata and trichome-hydathodes on the upper surface were significant at P = 0.05. The size of stomatal aperture was, however, significant at P = 0.01. Bacterization of seeds with Rhizobium increased the number of stomata and trichome-hydathodes, size of stomata and stomatal aperture and the length of trichome-hydathodes in comparison to plants from non-bacterised seeds. The increase was greater in unpolluted soil than polluted soils. Both M. incognita and M. javanica reduced the number of stomata and trichome-hydathodes, size of stomata and stomatal aperture and the length of trichome hydathodes. The reductions caused by M. javanica in number of trichome-hydathodes on upper surface and the length of trichome-hydathodes were significant only at P = 0.05. The suppression in the size of stomata caused by M. javanica was not significant. In the presence of Rhizobium, the adverse

effects of M. incognita and M. javanica on epidermal characters were reduced. Rhizobium reduced the suppressive effect of M. incognita on stomatal counts on both surfaces of leaves. On the upper leaf surface, the difference was significant only at P = 0.05. Rhizobium, however, did not influence the adverse effects of M. incognita on size of stomata and trichome-hydathodes. The number of trichome-hydathodes, however, increased on the upper leaf surface. Addition of Rhizobium with M. javanica further reduced the adverse effects of the nematode and increased the epidermal parameters. Individual effects (positive or negative) of M. incognita and M. javanica or in combination with Rhizobium were greater in unpolluted soil than polluted soils (Table 6).

In contrast to trichome-hydathodes, the number and length of trichomes were significantly decreased in the flyash polluted soils. This suppressive effect was greater in S_1 soil than in S_2 soil (Table 6). Number and length of trichomes in Rhizobium inoculated plants were lower than plants from non-bacterized seeds. This effect was also smaller in polluted soils.

Root-knot nematodes increased the number and length of trichomes. The increase in length of trichomes on lower surface was significant only at P = 0.05. M. incognita and M. javanica together with Rhizobium suppressed trichome

Table 6. Interactive effects of ambient flyash polluted soils, root-knot nematodes and root nodule bacteria on some epidermal characters of leaves in chick-pea.

Treatments		No. of stomata /cm^2					Size of stomata(μm^2)					Size of stomatal aperture(μm^2)				
					L.S.D.					L.S.D.					L.S.D.	
		C	S_1	S_2	0.01	0.05	C	S_1	S_2	0.01	0.05	C	S_1	S_2	0.01	0.05
P (Control)	L	24992.12	28241.10	25991.81	745.81	512.48	396.33	428.04	404.26	15.64	10.76	86.44	93.35	90.76	7.06	4.85
	U	13884.45	15967.12	14856.36	654.30	449.72	378.45	420.08	395.48	19.82	13.62	62.50	68.25	66.87	4.10	2.82
P+Rh	L	30240.45	31912.44	30722.32	693.86	476.91	459.74	475.12	464.43	11.51	7.91	96.81	98.02	99.84	5.69	3.91
	U	17160.17	18202.52	17887.06	579.99	398.65	446.57	473.01	455.99	17.36	11.93	71.88	78.06	75.43	3.93	2.70
P+Mi	L	23140.26	27154.90	24359.71	712.97	490.05	360.61	403.05	374.31	13.20	9.07	75.17	85.64	80.32	5.30	3.64
	U	12452.02	15021.81	13705.13	608.22	418.42	340.94	393.70	362.16	20.41	14.03	53.65	62.05	58.76	2.97	2.04
P+Rh+Mi	L	25916.74	28794.20	26795.68	578.35	397.52	402.27	430.46	408.09	12.28	8.44	81.18	89.92	85.54	5.98	4.11
	U	14344.72	16282.56	15500.56	689.52	473.93	387.26	425.20	401.99	18.54	12.74	59.55	66.39	64.28	3.59	2.47
P+Mj	L	23801.36	27418.54	24992.13	606.45	416.83	376.89	410.79	385.11	11.26	7.74	78.58	87.24	83.11	4.98	3.42
	U	12879.11	15294.18	14068.52	713.67	490.53	352.69	402.38	373.09	20.24	13.91	55.31	62.69	60.24	3.19	2.19
P+Rh+Mj	L	27847.42	30160.40	28740.94	660.10	453.71	429.65	447.76	436.67	13.43	9.23	86.59	93.35	90.86	4.47	3.07
	U	15352.25	17236.54	16460.17	686.49	471.85	410.12	442.61	422.34	16.98	11.67	61.95	68.05	66.27	4.42	3.04
L.S.D.																
0.01	L	678.46	609.40	642.70			29.42	26.57	27.65			7.80	7.49	8.21		
	U	520.92	538.14	514.05			31.48	32.38	29.66			6.59	7.35	7.04		
0.05	L	497.46	446.82	471.24			21.57	19.48	20.27			5.72	5.49	6.02		
	U	381.95	394.57	376.91			23.08	23.74	21.75			4.83	5.39	5.16		

L = Lower surface, U = Upper surface

Each value is mean of five replicates.

Table 6 (Continued)

Treatment		No. of trichome-hydathodes/cm^2					Length of trichome-hydathodes (μm)					No. of trichomes/cm^2					Length of trichomes(μm)				
		C	S_1	S_2	L.S.D. 0.01	L.S.D. 0.05	C	S_1	S_2	L.S.D. 0.01	L.S.D. 0.05	C	S_1	S_2	L.S.D. 0.01	L.S.D. 0.05	C	S_1	S_2	L.S.D. 0.01	L.S.D. 0.05
P (Control)	L	651.39	716.53	696.98	34.73	23.87	424.56	457.92	440.96	33.95	24.71	3039.57	2738.35	2840.72	142.30	97.81	331.25	309.57	318.51	17.21	11.83
	U	411.40	464.88	450.07	28.01	19.25	404.13	443.56	427.17	23.70	16.29	1651.24	1404.12	1514.90	99.36	68.29	321.75	296.27	304.98	19.60	13.47
P+Rh	L	1097.02	1150.46	1129.11	43.78	30.09	562.22	573.08	564.43	27.99	19.24	1885.58	1801.42	1832.72	100.85	69.32	238.65	238.69	237.69	13.15	9.04
	U	1028.16	939.06	987.15	60.74	41.75	545.76	566.81	557.03	22.93	15.76	988.62	961.73	966.14	63.61	43.72	230.11	224.46	224.25	10.93	7.51
P+Mi	L	497.24	592.17	548.80	39.88	27.11	375.22	427.83	397.26	33.32	22.90	3556.30	3039.57	3255.47	149.77	102.94	371.00	333.10	350.36	19.31	13.27
	U	304.74	381.05	346.21	32.76	22.52	351.42	407.85	380.04	26.89	18.48	2030.73	1642.82	1826.97	70.69	70.64	380.93	325.90	342.79	21.27	14.62
P+Rh+Mi	L	721.00	793.51	773.81	49.86	34.27	446.51	470.61	456.85	37.49	25.77	2694.17	2432.97	2543.33	135.80	93.34	304.10	292.78	294.42	15.16	10.42
	U	624.72	653.74	648.74	29.67	20.39	428.73	456.79	448.45	25.24	17.35	1430.09	1283.45	1343.36	91.94	63.19	322.82	293.60	297.05	18.01	12.38
P+Mj	L	552.03	651.39	606.07	33.22	22.83	388.90	436.11	408.30	31.37	21.56	3373.92	2930.03	3119.10	143.39	98.56	361.06	331.24	343.99	19.15	13.16
	U	340.04	422.68	384.68	36.62	25.17	364.08	419.40	391.18	29.29	20.13	1925.16	1558.57	2151.16	108.23	74.39	367.68	322.93	335.48	23.60	16.22
P+Rh+Mj	L	866.69	931.95	915.17	42.89	29.48	482.24	518.53	489.96	30.33	20.85	2249.28	2236.67	2296.56	107.43	73.84	284.29	278.11	280.58	12.38	8.51
	U	782.14	773.39	781.64	31.61	21.73	460.56	486.49	475.29	27.09	18.62	1212.43	1146.01	1463.37	104.58	71.88	285.02	268.67	270.55	21.71	14.92
L.S.D.																					
0.01	L	97.45	115.10	96.78			40.53	42.39	44.67			173.80	180.72	182.51			31.04	32.58	27.15		
	U	90.27	87.04	91.77			47.58	46.60	47.76			171.41	163.38	193.23			37.38	31.46	40.21		
0.05	L	71.45	84.39	70.96			29.72	31.08	32.75			127.43	132.51	133.82			22.76	23.89	19.91		
	U	66.19	63.82	67.29			34.89	34.17	35.02			125.68	119.94	141.68			27.41	23.07	29.48		

L = Lower surface, U = Upper surface

Each value is mean of five replicates.

length and count. The reduction in the length due to M. incognita and Rhizobium was significant only at P = 0.05. The effects of M. incognita and M. javanica alone and in combination with Rhizobium were greater in the unpolluted soil than polluted soils in comparison to their respective checks.

LENTIL, Lens culinaris Medic.

Plant growth and yield

Plant growth of lentil increased in the flyash polluted soils of both the sites. The growth was relatively better in S_1 soil than S_2 soil. Increase in length and fresh weight of shoot and root were significant in S_1 and S_2 soils while the increase in dry weights of shoot and root was significant at P = 0.05 in S_2 soil and at P = 0.01 in S_1 soil. Rhizobium inoculation improved all the growth parameters and this influence was relatively greater in unpolluted soil than polluted soils. M. incognita and M. javanica caused reductions in plant growth. The reductions were relatively greater in unpolluted soil. M. incognita was more inhibitory than M. javanica. Reduction in root length by M. javanica was, however, not significant and the reduction in the dry weights of shoot and root was significant only at P = 0.05. M. incognita together with Rhizobium also decreased the shoot length (P = 0.01) and root length (at P = 0.05). A non-significant decrease in fresh weights and a slight increase in dry weights of

Table 7. Interactive effects of ambient flyash polluted soil, root-knot nematodes and root nodule bacteria on plant growth and yield characters of lentil.

Treatment		Length (cm)			L.S.D.		Fresh weight (g)			L.S.D.		Dry weight (g)			L.S.D.		Flower/Fruit			L.S.D.	
		C	S_1	S_2	0.01	0.05	C	S_1	S_2	0.01	0.05	C	S_1	S_2	0.01	0.05	C	S_1	S_2	0.01	0.05
P (Control)	S	31.4	36.5	33.0	2.39	1.64	16.50	26.10	19.10	2.11	1.45	3.15	5.10	3.70	0.74	0.51	FL 52.4	78.0	60.2	7.26	4.99
	R	17.0	23.4	20.6	3.26	2.24	12.50	19.55	14.50	1.94	1.33	2.85	3.95	3.35	0.52	0.36	FR 35.8	55.2	43.0	5.48	3.77
P+Rh	S	38.7	42.0	39.2	2.85	1.96	23.75	34.20	26.15	2.95	2.05	4.65	6.65	5.05	0.83	0.57	FL 80.2	98.6	89.2	7.39	5.08
	R	21.5	26.4	24.3	2.87	1.97	19.60	27.75	21.95	2.24	1.54	4.25	5.50	4.90	0.39	0.27	FR 60.2	81.6	68.4	5.14	3.53
P+Mi	S	24.2	31.3	26.8	2.52	1.73	12.95	22.50	15.40	2.71	1.86	2.55	4.40	3.10	0.61	0.42	FL 42.2	66.2	49.8	6.85	4.71
	R	13.3	20.0	16.6	2.53	1.74	8.75	15.05	10.60	1.69	1.16	2.35	3.40	2.80	0.36	0.25	FR 26.4	43.8	33.2	5.47	3.76
P+Rh+Mi	S	27.5	34.4	29.5	2.72	1.87	16.40	25.85	18.65	2.02	1.39	3.25	5.20	3.80	0.57	0.39	FL 57.4	84.6	65.2	6.15	4.23
	R	15.4	21.2	18.5	3.10	2.13	11.35	18.50	13.55	1.80	1.24	3.15	4.25	3.65	0.55	0.38	FR 39.4	60.8	47.4	5.97	4.10
P+Mj	S	26.8	33.5	28.9	2.78	1.91	14.50	24.25	17.35	2.39	1.64	2.80	4.75	3.35	0.41	0.28	FL 47.2	72.8	55.2	6.45	4.43
	R	16.5	21.7	18.3	2.26	1.55	10.45	17.55	12.65	1.73	1.19	2.55	3.70	3.06	0.45	0.31	FR 31.4	50.4	38.4	5.72	3.93
P+Rh+Mj	S	32.4	37.2	33.8	2.66	1.83	19.85	29.60	22.90	2.49	1.71	3.90	6.00	4.40	0.64	0.44	FL 67.4	96.2	76.2	7.43	5.11
	R	19.7	23.9	21.1	2.82	1.94	15.50	22.10	17.20	1.89	1.30	3.55	4.80	4.10	0.36	0.25	FR 49.2	72.4	57.2	6.13	4.2
L.S.D.																					
0.01	S	2.92	3.76	4.26			1.83	3.15	2.96			0.46	0.55	0.56			FL 7.80	6.67	6.53		
	R	1.62	2.55	2.78			1.66	2.62	2.54			0.30	0.52	0.35			FR 4.69	7.73	5.71		
0.05	S	2.14	2.76	3.12			1.34	2.31	2.17			0.34	0.40	0.41			FL 5.72	4.96	4.79		
	R	1.19	1.87	2.04			1.22	1.92	1.86			0.22	0.38	0.26			FR 3.44	5.67	4.19		

S = Shoot, R = Root

FL = Flower, FR = Fruit

Each value is mean of five replicates.

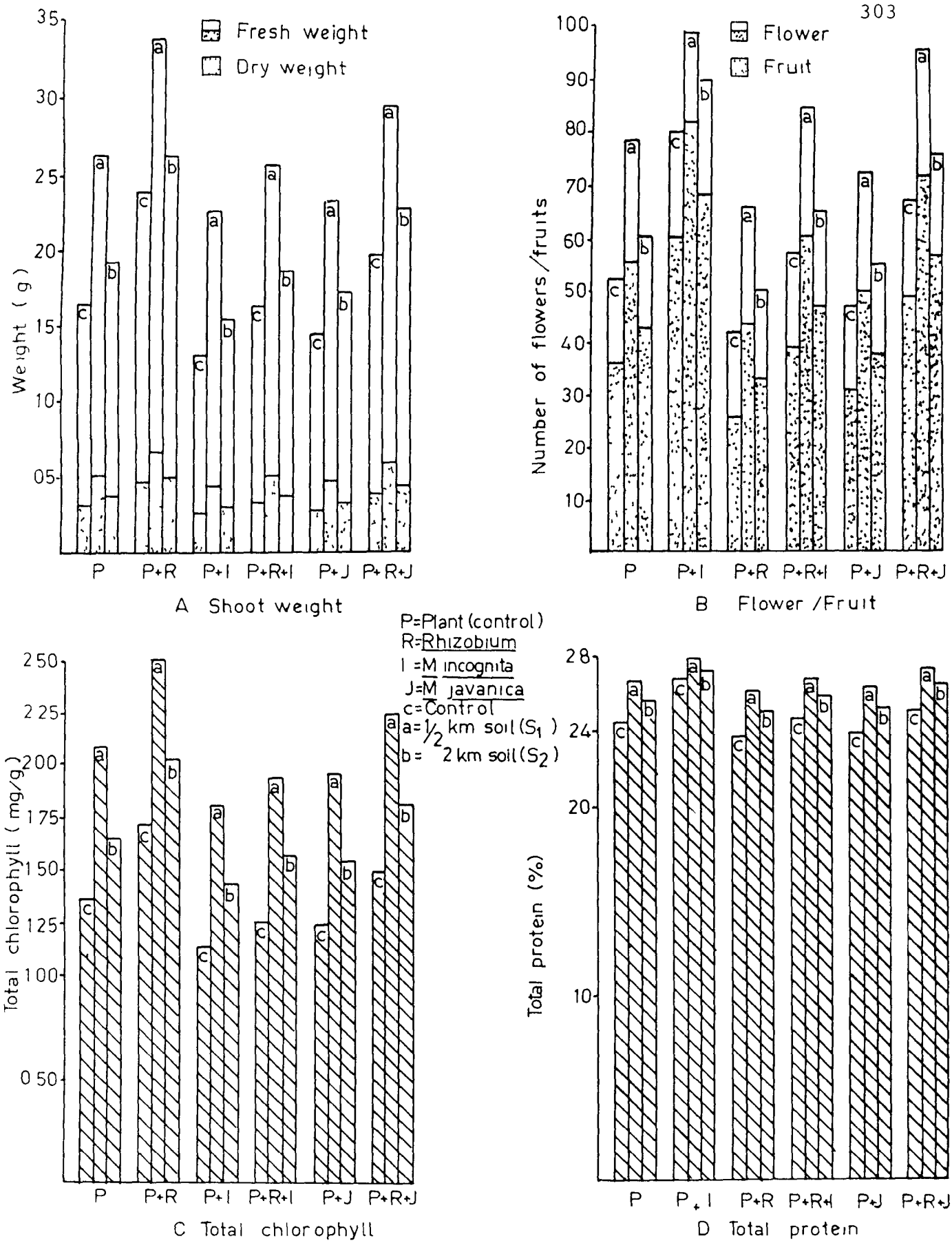

Fig 2 Interactive effects of ambient flyash polluted soil, roo-knot nematodes and root nodule bacteria on some parameters of lentil

root and shoot were recorded. The increase in dry weight of shoot was not significant but increase in root dry weight was significant at P = 0.05. M. javanica alongwith Rhizobium increased all the growth parameters except shoot length (Table 7, Fig. 2A).

The yield parameters (flowers and fruits/plant) were increased significantly in the flyash polluted soils. The increase in number of flowers and fruits was greater in S_1 soil than S_2 soil. Rhizobium inoculation also increased the yield parameters and the increase was relatively greater in unpolluted soil than polluted soils. M. incognita and M. javanica adversely affected the flowering and fruiting. The reduction caused by M. javanica was significant only at P = 0.05. Rhizobium even in the presence of M. incognita or M. javanica increased the yield parameters. This increase with M. incognita was not significant and with M. javanica at P = 0.01. These effects of M. incognita and M. javanica alone or in combination with Rhizobium, were suppressed in polluted soil, being least in polluted soil of S_2 (Table 7, Fig. 2B).

Root-knot disease and root nodulation

M. incognita and M. javanica, both caused galling and reproduced on lentil but the root galling and eggmass production of M. incognita was greater than M. javanica. Root galling and eggmass production were inhibited

Table 8. Interactive effects of ambient flyash polluted soil, root-knot nematodes and root nodule bacteria on root galling, eggmass production, bacterial nodulation, leaf chlorophyll content and protein content of seeds of lentil.

Treatment		Gall/Eggmass			L.S.D.		Nodule			L.S.D.		Chlorophyll(mg/g)			L.S.D.		Protein(%)			L.S.D.	
		C	S_1	S_2	0.01	0.05	C	S_1	S_2	0.01	0.05	C	S_1	S_2	0.01	0.05	C	S_1	S_2	0.01	0.05
P (Control)												A 0.724	1.083	0.904	0.100	0.069	S 10.46	10.62	10.58	0.15	0.10
												B 0.563	0.960	0.711	0.111	0.076	I 13.94	16.02	15.08	0.28	0.19
												T 1.362	2.087	1.659	0.189	0.130	T 24.40	26.64	25.66	0.33	0.23
P+Rh							T 226.4	131.6	190.8	12.61	8.67	A 0.902	1.302	1.102	0.124	0.085	S 11.56	11.91	11.12	0.30	0.14
							F 203.2	109.4	161.6	12.41	8.53	B 0.714	1.153	0.868	0.119	0.082	I 15.28	16.72	16.08	0.21	0.15
												T 1.716	2.505	2.024	0.198	0.136	T 26.84	27.91	27.20	0.32	0.22
P+Mi	G	136.4	160.2	146.4	8.19	5.63						A 0.594	0.934	0.767	0.080	0.055	S 10.16	10.32	10.28	0.16	0.11
	E	93.2	22.2	52.4	7.11	4.89						B 0.457	0.829	0.603	0.090	0.062	I 13.52	15.80	14.66	0.29	0.20
												T 1.129	1.798	1.430	0.138	0.095	T 23.68	26.12	24.96	0.43	0.33
P+Rh+Mi	G	107.2	144.0	130.2	6.97	4.79	T 154.6	108.4	140.4	10.82	7.44	A 0.648	1.004	0.838	0.124	0.085	S 10.60	10.72	10.68	0.17	0.12
	E	70.6	18.4	42.6	6.07	4.17	F 110.4	70.8	96.2	9.44	6.49	B 0.496	0.891	0.660	0.106	0.073	I 14.07	16.08	15.16	0.25	0.17
							I 25.8	40.2	32.4	5.27	3.62	T 1.252	1.934	1.566	0.188	0.129	T 24.64	26.80	25.84	0.35	0.24
P+Mj	G	64.4	84.6	75.6	6.23	4.28						A 0.664	1.012	0.834	0.116	0.080	S 10.26	10.44	10.38	0.21	0.15
	E	37.8	18.0	28.4	5.30	3.64						B 0.503	0.898	0.656	0.103	0.071	I 13.66	15.94	14.84	0.26	0.18
												T 1.244	1.951	1.530	0.207	0.142	T 23.92	26.38	25.22	0.41	0.28
P+Rh+Mj	G	52.8	70.4	65.8	6.27	4.31	T 196.0	120.8	176.2	13.30	9.14	A 0.788	1.159	0.974	0.106	0.073	S 10.88	10.94	10.90	0.13	0.09
	E	34.2	15.2	26.6	5.43	3.73	F 151.4	85.6	131.4	12.85	8.83	B 0.621	1.028	0.767	0.090	0.060	I 14.24	16.46	15.58	0.26	0.18
							I 16.4	27.4	20.2	3.62	2.49	T 1.481	2.234	1.790	0.176	0.121	T 25.12	27.40	26.48	0.33	0.23
L.S.D.																					
0.01	G	12.24	14.71	15.74			T 23.77	10.85	18.17			A 0.079	0.108	0.095			S 0.40	0.35	0.30		
	E	7.89	1.67	5.45			F 24.08	11.71	22.71			B 0.059	0.089	0.090			I 0.34	0.26	0.37		
							I 4.10	6.10	6.75			T 0.139	0.161	0.176			T 0.85	0.48	0.50		
0.05	G	8.73	10.49	11.23			T 16.34	7.46	12.49			A 0.058	0.079	0.070			S 0.29	0.26	0.22		
	E	5.63	1.19	3.89			F 16.55	8.05	15.61			B 0.043	0.065	0.066			I 0.25	0.19	0.27		
							I 2.47	3.68	4.07			T 0.102	0.118	0.129			T 0.62	0.35	0.37		

G = Gall, E = Eggmass

T = Total, F = Functional, I = Infected

A = Chl.a, B = Chl.b, T=Total Chl.

S = Soluole, I = Insoluble, T=Total

Each value is mean of five replicates.

significantly in the polluted soils. In the presence of Rhizobium, less number of galls and eggmasses developed. This impact of Rhizobium was smaller in the polluted soils than unpolluted soil (Table 8).

Root nodulation by Rhizobium was significantly inhibited in the flyash polluted soils. The inhibition of root nodulation and death of nodules was greater in S_1 soil than S_2 soil. Both M. incognita and M. javanica inhibited the nodulation and the number of functional nodules. Consequently, number of non-functional nodules increased. The number of functional nodules in the presence of M. incognita or M. javanica was less in the polluted soils than in unpolluted soil. The infection of bacterial nodules by root-knot nematodes was promoted by the polluted soils (Table 8).

Leaf pigments and seed proteins

Leaf pigment and seed protein contents were significantly increased in flyash polluted soils. The increase in soluble protein content in S_2 soil was, however, significant only at $P = 0.05$. The chlorophyll and protein contents were also greater in the plants inoculated with Rhizobium than plants without Rhizobium. Both M. incognita and M. javanica acting alone reduced the chlorophyll and protein contents. Reduction in chlorophyll a and total chlorophyll caused by M. javanica was significant only

at p = 0.05. Reductions in soluble and total proteins caused by M. incognita were significant only at P = 0.05. M. javanica, however, caused significant reduction (at P = 0.05) of only insoluble protein. M. incognita together with Rhizobium increased the chlorophyll a (at P = 0.05) and chlorophyll b and total chlorophyll (at p = 0.01). The increase in protein content obtained with inoculation of M. incognita and Rhizobium was not significant. M. javanica along with Rhizobium increased the chlorophyll and protein contents (at P = 0.05). The increase in soluble protein only was significant at P = 0.01. M. incognita and M. javanica acting alone reduced chlorophyll and protein contents. When combined with Rhizobium the reductions caused by the nematodes were comparatebly smaller. The effects of root-knot nematodes alone or with Rhizobium were less in polluted soils (Table 8, Figs. 2C and 2D).

Leaf epidermal characters

The number and size of stomata and size of stomatal aperture were variously influenced in the flyash polluted soils of both the sites. The influences were greater in S_1 soil than in S_2 soil. All the epidermal characters were significantly affected in S_1 soil. In S_2 soil, increase in the number and size of stomata recorded on the lower surface was not significant. But on the upper surface the increase was significant at P = 0.05. The size of

stomatal aperture increased significantly on lower surface (at P = 0.05) and on upper surface (at P = 0.01). Rhizobium increased the number and size of stomata and size of stomatal aperture. The increase in the size of stomatal aperture on the lower surface was significant only at P = 0.05. M. incognita and M. javanica individually caused reduction in the number and size of stomata and size of stomatal aperture (Table 9). These decreasing effects of root-knot nematodes was reduced by the presence of Rhizobium. M. incognita and Rhizobium together decreased the number and size of stomata and size of stomatal aperture in comparison to check. This reduction in number of stomata on the upper surface was not significant. The reduction in the size of stomatal aperture on the upper surface was significant at P = 0.05. M. javanica in the presence of Rhizobium increased stomatal count non-significantly. But decrease in the size of stomata and stomatal aperture occurred in comparison to check. These effects of M. incognita and M. javanica alone and in combination with Rhizobium were greater in unpolluted soil (Table 9).

Number and length of trichomes were significantly decreased in the polluted soils. The reduction in the number of trichomes on upper surface was significant only at P = 0.05. The number and length of trichomes on the leaves of plants with bacterial nodulation were smaller. M. incognita and M. javanica individually increased the

Table 9. Interactive effects of ambient flyash polluted soils, root-knot nematodes and root nodule bacteria on some epidermal characters of leaves of lentil.

Treatment		No. of stomata/cm^2			L.S.D.		Size of stomata (µm)			L.S.D.		Size of stomatal aperture (µm^2)			L.S.D.	
		C	S_1	S_2	0.01	0.05	C	S_1	S_2	0.01	0.05	C	S_1	S_2	0.01	0.05
P (Control)	L	4936.83	5479.88	5084.93	275.54	189.39	660.44	726.48	680.25	42.42	29.16	86.44	92.49	91.63	5.25	3.61
	U	3538.06	3980.32	3700.81	179.58	123.43	591.12	663.68	620.68	36.17	24.86	69.15	75.17	74.68	3.61	2.48
P+Rh	L	5430.51	5808.67	5491.72	316.40	217.47	713.28	785.21	734.68	45.71	31.42	92.49	95.26	97.13	5.47	3.76
	U	3963.18	4298.75	4052.39	166.16	114.21	656.14	690.38	676.54	45.89	31.54	75.37	78.18	69.91	3.65	2.51
P+Mj	L	4485.03	5169.70	4708.27	243.72	167.52	582.91	678.95	607.37	40.07	27.54	77.18	87.25	83.30	[illegible]	3.89
	U	3173.15	3719.93	3395.24	190.24	131.09	517.62	620.40	554.18	42.45	29.18	60.66	69.60	66.68	3.17	2.18
P+Rh+Mj	L	4754.14	5339.79	4943.68	230.37	158.34	609.14	689.13	625.59	45.71	31.42	80.26	88.56	85.30	[illegible]	3.63
	U	3458.73	3909.32	3628.32	186.01	127.85	548.67	635.91	576.35	35.66	24.51	63.39	71.34	69.01	3.40	2.34
P+Mj	L	4613.86	5320.27	4819.84	269.43	185.19	594.98	685.36	624.08	38.42	26.41	78.56	88.93	84.30	5.47	3.76
	U	3251.89	3827.23	3474.94	195.22	134.18	527.79	623.31	563.23	31.56	21.69	61.74	70.92	67.77	4.18	2.87
P+Rh+Mj	L	5028.17	5567.29	5173.23	201.85	138.74	636.64	705.92	657.78	55.85	38.39	82.49	90.71	87.67	5.06	3.48
	U	3659.08	4076.02	3811.83	210.06	144.38	575.29	648.24	602.66	37.73	25.93	66.14	73.05	71.29	3.72	2.56
L.S.D.																
0.01	L	228.43	192.43	212.60			46.47	36.47	42.89			7.45	6.91	5.37		
	U	176.70	177.83	167.40			40.47	43.44	40.53			4.73	3.79	4.84		
0.05	L	167.49	141.09	155.88			34.07	26.74	31.45			5.46	5.07	3.94		
	U	129.56	130.39	122.74			29.67	31.85	29.72			3.47	2.78	3.55		

L = Lower surface, U = Upper surface

Each value is mean of five replicates

Table 9. (Continued)

		Number of trichomes/cm^2					Length of trichomes (μm)				
					L.S.D.					L.S.D.	
		C	S_1	S_2	0.01	0.05	C	S_1	S_2	0.01	0.05
P (Control)	L	2591.84	2215.25	2356.62	179.67	123.49	733.17	672.63	698.26	34.73	23.87
	U	1548.53	1303.48	1375.25	198.94	136.74	680.16	616.09	635.66	32.24	22.16
P+Rh	L	1963.52	1786.49	1826.53	227.46	156.34	591.26	574.90	577.08	41.45	28.49
	U	1082.87	1002.78	1026.31	205.46	141.22	507.58	588.14	496.61	26.39	18.14
P+Mi	L	2901.94	2348.17	2596.55	202.11	138.92	784.49	698.19	737.36	33.06	22.72
	U	1773.05	1405.15	1536.15	202.83	139.41	741.37	645.66	680.16	34.25	23.54
P+Rh+Mi	L	2545.63	2194.55	2318.55	207.19	142.07	694.23	652.51	664.29	36.61	25.16
	U	1453.42	1265.90	1312.95	173.02	118.92	633.65	592.35	599.26	30.71	21.11
P+Mj	L	2825.11	2281.94	2532.94	189.01	129.91	762.50	689.45	722.04	34.80	25.92
	U	1718.87	1373.87	1496.27	212.98	146.39	718.25	637.65	664.26	34.51	23.72
P+Rh+Mj	L	2243.15	1966.99	2076.18	217.35	149.24	630.17	605.58	611.87	28.82	19.81
	U	1282.74	1144.87	1187.52	203.00	139.53	552.56	528.02	531.41	26.68	19.71
L.S.D.											
0.01	L	172.89	130.12	146.44			56.04	27.92	33.43		
	U	169.49	110.50	126.66			40.11	31.60	37.36		
0.05	L	126.84	95.41	107.37			41.09	20.47	24.57		
	U	124.27	81.02	92.87			29.41	23.17	27.39		

L = Lower surface, U = Upper surface

Each value is mean of five replicates.

number of trichomes. M. incognita increased the length of trichomes on lower (at P = 0.05) and upper (at P=0.01) surfaces. Increase in length of trichomes due to M. javanica was not significant on the lower surface. But it was significant (at P = 0.05) on the upper surface. Along with Rhizobium, M. incognita did not significantly decrease the number and length of trichomes except the length, on upper leaf surface (significant at P = 0.05). M. javanica, even in the presence of Rhizobium, on the other hand, caused significant reduction in number and length of trichomes. These effects were greater in unpolluted soil than polluted soils (Table 9).

Part B - FLYASH AMENDED SOIL

Seed germination

Seed germination of both chick-pea and lentil was adversely affected in the soil artificially amended with flyash. The reduction was correlated with flyash content of the soil. The reduction in seed germination of chick-pea and lentil was 5.56% and 2.33% at 10% flyash level. Stepwise greater reduction occurred with the increasing level of flyash in soil and at 80% flyash level per cent reduction was 61.11 in chick-pea and 55.81 in lentil. Seed germination of chick-pea was relatively more suppressed in flyash amended soils than lentil. The per cent germination observed at 80 to 100% flyash levels was more or less same for both the crops (Table 10).

The survival of seedlings after emergence was also influenced by the flyash content of the soil. The seedling mortality showed stepwise increase upto 60% flyash level. Thereafter, it decreased marginally and remained almost same in 80-100% flyash levels. The seedling mortality was greater in lentil than chick-pea (Table 10).

Table 10. Seed germination of chick-pea and lentil in flyash amended soils.

Flyash level in soil (%) v/v	Chick-pea			Lentil		
	Seed germination %	Reduction over control %	Seedling mortality %	Seed germination %	Reduction over control %	Seedling mortality %
00 (control)	90		2	86		4
10	85	5.56	1	84	2.33	5
20	77	14.44	4	79	8.14	7
30	74	17.78	8	76	11.63	11
40	70	22.22	11	71	17.44	14
50	61	32.22	15	65	24.42	18
60	52	42.22	18	56	34.88	21
70	44	51.11	12	48	44.19	19
80	35	61.11	10	38	55.81	13
90	35	61.11	9	37	56.98	13
100	34	62.22	9	37	56.98	12

Juvenile hatching

The hatching of juveniles (J_2) of both M. incognita and M. javanica was inhibited by the flyash amended soil. The number of hatched juveniles showed stepwise decrease with the increasing level of flyash. The juveniles of M. incognita failed to hatch out in the soil having 80%

Table 11. Hatching of juveniles (J_2) of Meloidogyne incognita and Meloidogyne javanica in flyash amended soils.

Flyash level in soil(v/v) (%)	M. incognita		M. javanica	
	Juveniles/ eggmass	Reduction over control (%)	Juveniles / eggmass	Reduction over control (%)
00(control)	269		256	
10	237	11.90	231	9.77
20	206	23.42	197	23.05
30	147	45.35	138	46.09
40	118	56.13	126	50.78
50	106	60.59	118	53.91
60	92	65.80	102	60.16
70	76	71.75	90	64.84
80	00	100.00	31	87.89
90	00	100.00	00	100.00
100	00	100.00	00	100.00

of flyash. For M. javanica, complete inhibition of juvenile hatching occurred at 90% flyash level. At 70% flyash level, the reduction in juvenile hatching of M. incognita and M. javanica was 71.75 and 64.84% respectively. At 80%,

the reduction in juveinle hatching of M. javanica was 87.89%. The inhibition in the hatching of juvenile of M. incognita was greater that M. javanica (Table 11).

CHICK-PEA, Cicer arietinum L.

Plant growth and yield

Rhizobium, M. incognita and M. javanica in the control (unpolluted) soil affected the plant growth parameters (length, fresh and dry weights of shoot and root) and yield characters (number of flowers and fruits/plant) variously. The pattern in individual effects of Rhizobium, M. incognita and M. javanica was same as given in Part A of this section. The growth parameters of the plant (without any association) showed stepwise increase with the increasing level of flyash in the soil from 10% upto 50% but the increase in plant growth and yield parameters showed an abrupt decline at 60% flyash level. The increase in length of root was not significant at 60% while for all other growth and yield parameters, the increase was significant. At 70%, all the parameters exhibited decrease except shoot length which was not significantly greater than control soil. The decreases in root length, shoot dry weight and number of flowers were significant at $P = 0.01$ but decreases in fresh weight of shoot and dry weight of root were significant at $P = 0.05$. The decreases in fresh weight of root and number of flowers were not significant. All these growth and yield parameters again

Table 12. Interactive effects of flyash amended soil, root-knot nematodes & root-nodule bacteria on plant length and fresh weight of chick-pea.

Fly ash (%)		Length (cm)						L.S.D.		Fresh weight (g)						L.S.D.	
		P	P+Rh	P+Mi	P+Rh+Mi	P+Mj	P+Rh+Mj	0.01	0.05	P	P+Rh	P+Mi	P+Rh+Mi	P+Mj	P+Rh+Mj	0.01	0.05
0.0 (Control)	S	32.6	42.4	25.2	30.7	29.3	38.4	3.72	2.73	25.25	38.55	21.85	30.40	24.15	34.15	2.03	1.49
	R	22.7	27.5	16.4	19.6	19.8	23.9	1.73	1.27	17.50	24.25	14.80	18.30	16.75	21.85	1.55	1.14
10	S	35.1	43.5	27.3	32.5	33.2	39.6	3.83	2.81	28.45	40.15	23.15	31.25	26.26	37.45	2.25	1.65
	R	23.2	27.9	17.5	20.5	20.3	24.4	1.69	1.24	19.00	24.45	15.65	19.75	17.50	22.55	1.90	1.39
20	S	38.7	45.5	30.9	35.5	34.8	40.2	3.81	2.79	29.50	41.55	25.26	33.10	28.75	40.50	2.00	1.47
	R	24.5	29.6	20.4	23.2	23.4	26.1	1.79	1.31	20.15	25.25	17.10	20.65	18.60	22.70	1.91	1.40
30	S	42.2	48.6	35.6	41.4	38.5	44.6	3.34	2.45	31.50	43.00	28.25	35.85	30.50	40.85	2.17	1.59
	R	25.5	30.4	21.6	25.4	24.7	28.6	1.75	1.28	21.75	28.30	20.10	23.80	21.00	25.20	1.85	1.36
40	S	45.3	51.4	40.8	45.0	43.2	48.4	3.85	2.82	36.10	48.25	33.15	40.25	34.50	45.20	2.20	1.61
	R	28.2	33.9	24.1	27.2	26.5	29.0	2.09	1.53	24.25	29.15	21.25	24.05	22.75	27.15	2.07	1.52
50	S	51.3	56.4	46.3	50.2	49.5	53.1	4.15	3.04	42.15	54.10	39.50	46.60	40.85	51.45	1.62	1.19
	R	32.4	36.5	29.3	32.6	32.4	34.7	2.32	1.70	28.25	32.75	26.85	30.25	28.15	31.35	1.83	1.34
60	S	43.7	45.9	41.2	43.5	42.8	43.5	3.19	2.34	32.55	35.70	30.95	33.25	31.15	33.85	1.69	1.24
	R	24.6	26.2	22.2	23.5	22.7	24.2	1.76	1.29	22.50	25.60	21.25	23.75	21.70	23.85	1.61	1.18
70	S	35.0	35.1	34.2	34.2	33.4	33.6	1.96	1.44	23.40	23.40	22.25	22.25	21.80	21.80	1.46	1.07
	R	19.3	19.3	18.1	18.1	17.8	17.8	1.31	0.96	16.45	16.50	15.55	15.60	14.50	14.55	1.39	1.02
80	S	24.4	24.2	24.3	24.4	24.1	24.3	0.86	0.63	12.45	12.25	12.35	12.45	12.50	12.25	0.85	0.62
	R	14.3	14.3	14.4	14.4	14.2	14.3	0.79	0.58	9.50	9.50	9.45	9.40	9.45	9.35	0,42	0.31
90	S	16.6	16.7	16.4	16.6	16.6	16.5	0.38	0.28	8.15	8.05	8.10	8.15	8.15	8.20	0.19	0.14
	R	11.8	11.8	11.9	12.0	11.9	12.0	0.31	0.23	7.15	7.25	7.20	7.15	7.25	7.15	0.16	0.12
100	S	16.5	16.6	16.4	16.4	16.3	16.5	0.31	0.23	8.15	8.15	8.20	8.15	8.25	8.20	0.16	0.12
	R	12.0	11.8	11.7	12.0	11.8	11.8	0.26	0.19	7.20	7.25	7.15	7.20	7.25	7.20	0.18	0.13
L.S.D.																	
0.01	S	3.92	4.38	4.27	2.82	4.09	4.54			1.82	2.25	1.90	2.13	2.18	1.90		
	R	2.74	2.98	1.95	2.31	2.49	2.03			1.59	1.66	1.55	1.58	1.66	1.51		
0.05	S	2.94	3.27	3.19	2.86	3.06	3.39			1.36	1.68	1.42	1.59	1.63	1.42		
	R	2.05	2.23	1.46	1.73	1.86	1.52			1.19	1.24	1.16	1.18	1.24	1.13		

S = Shoot, R = Root

Each value is mean of five resplicates.

P = Plant, Rh = Rhizobium, Mi = Meloidogyne incognita, Mj = M. javanica. These abbreviations are common to all subsequent tables in the Section V B.

Table 13. Interactive effects of flyash amended soil, root-knot nematodes and root nodule bacteria on plant dry weight, flowering and fruiting of chick-pea.

Fly ash (%)		Dry weight (g) P	P+Rh	P+Mi	P+Rh+Mi	P+Mj	P+Rh+Mj	L.S.D. 0.01	L.S.D. 0.05	Flowers/Fruit P	P+Rh	P+Mi	P+Rh+Mi	P+Mj	P+Rh+Mj	L.S.D. 0.01	L.S.D. 0.05
00 (Control)	S	5.80	8.95	5.15	7.20	5.45	8.35	0.94	0.69	FL 96.8	150.4	58.8	70.2	70.4	98.2	6.30	4.62
	R	4.15	5.75	3.45	4.00	3.85	4.90	0.63	0.46	FR 64.6	110.2	35.8	45.4	48.0	67.2	5.40	3.96
10	S	6.55	9.35	5.40	7.55	6.15	8.95	0.87	0.64	FL 109.4	154.2	68.4	80.6	81.2	109.8	7.28	5.34
	R	4.25	5.70	3.55	4.05	4.00	5.05	0.72	0.53	FR 76.4	112.4	43.6	54.6	57.8	77.6	5.21	3.82
20	S	6.85	9.55	5.90	7.90	6.75	9.60	0.70	0.51	FL 123.6	160.2	80.4	93.6	94.2	121.8	7.38	5.41
	R	4.70	6.15	4.90	5.45	5.10	6.15	0.67	0.49	FR 91.4	116.6	55.4	67.8	71.2	89.2	6.30	4.62
30	S	7.30	10.05	6.65	8.55	7.15	9.85	0.57	0.42	FL 130.2	162.8	88.6	101.8	101.6	126.2	6.94	5.09
	R	5.30	6.70	4.90	5.45	5.10	6.15	0.70	0.51	FR 103.6	123.4	65.6	75.4	82.8	97.0	5.71	4.19
40	S	8.40	11.30	7.75	9.60	8.10	10.70	0.53	0.39	FL 148.4	173.6	110.0	122.8	121.4	140.2	6.79	4.91
	R	6.10	7.55	5.65	6.20	6.00	7.35	0.52	0.38	FR 119.4	135.2	82.6	93.2	101.6	115.2	5.84	4.28
50	S	9.85	12.75	8.35	11.05	9.65	12.05	0.53	0.39	FL 156.2	175.0	131.2	145.6	134.6	150.8	6.72	4.93
	R	7.05	8.30	6.65	7.25	7.00	8.15	0.40	0.29	FR 127.6	140.4	102.9	110.2	112.0	122.4	4.86	3.56
60	S	7.35	9.35	7.95	8.90	7.55	8.95	0.56	0.41	FL 133.6	144.2	120.4	128.8	119.2	126.4	5.01	3.67
	R	5.95	6.70	5.70	6.15	5.99	6.65	0.33	0.24	FR 105.8	113.2	93.2	100.2	96.2	102.0	4.08	2.99
70	S	4.65	4.80	4.35	4.40	4.25	4.35	0.26	0.19	FL 89.4	92.8	86.6	90.2	84.0	87.4	3.30	2.42
	R	3.75	3.95	3.80	3.85	3.75	3.95	0.21	0.16	FR 61.8	63.6	59.4	61.2	58.2	60.0	2.55	1.87
80	S	3.25	3.25	3.25	3.20	3.15	3.25	0.18	0.13	FL 31.6	30.8	31.8	31.4	31.4	31.6	1.57	1.15
	R	2.95	2.90	2.85	2.75	2.95	2.85	0.15	0.11	FR 23.6	23.8	23.4	23.6	23.0	23.2	1.04	0.76
90	S	2.45	2.30	2.35	2.40	2.50	2.35	0.10	0.07	FL 22.2	22.2	22.0	22.4	22.4	22.2	1.43	1.05
	R	2.30	2.35	2.20	2.25	2.35	2.30	0.08	0.06	FR 12.8	12.8	12.4	12.6	12.8	12.4	0.41	0.30
100	S	2.50	2.30	2.40	2.45	2.45	2.50	0.11	0.08	FL 22.4	22.0	22.4	22.2	22.6	22.4	1.46	1.07
	R	2.35	2.30	2.25	2.25	2.30	2.25	0.05	0.04	FR 12.4	12.8	12.4	12.4	12.6	12.8	0.48	0.35
L.S.D.																	
0.01	S	0.55	0.45	0.43	0.58	0.50	0.66			FL 5.03	4.58	5.69	5.57	5.30	5.43		
	R	0.43	0.50	0.39	0.35	0.37	0.43			FR 6.17	3.73	4.25	4.33	5.45	5.53		
0.05	S	0.41	0.34	0.32	0.43	0.37	0.50			FL 3.76	3.42	4.25	4.16	3.96	4.06		
	R	0.32	0.37	0.29	0.26	0.28	0.32			FR 4.61	2.79	3.18	3.24	4.07	4.13		

S = Shoot, R = Root

FL = Flower, FR = Fruit

Each value is mean of five replicates.

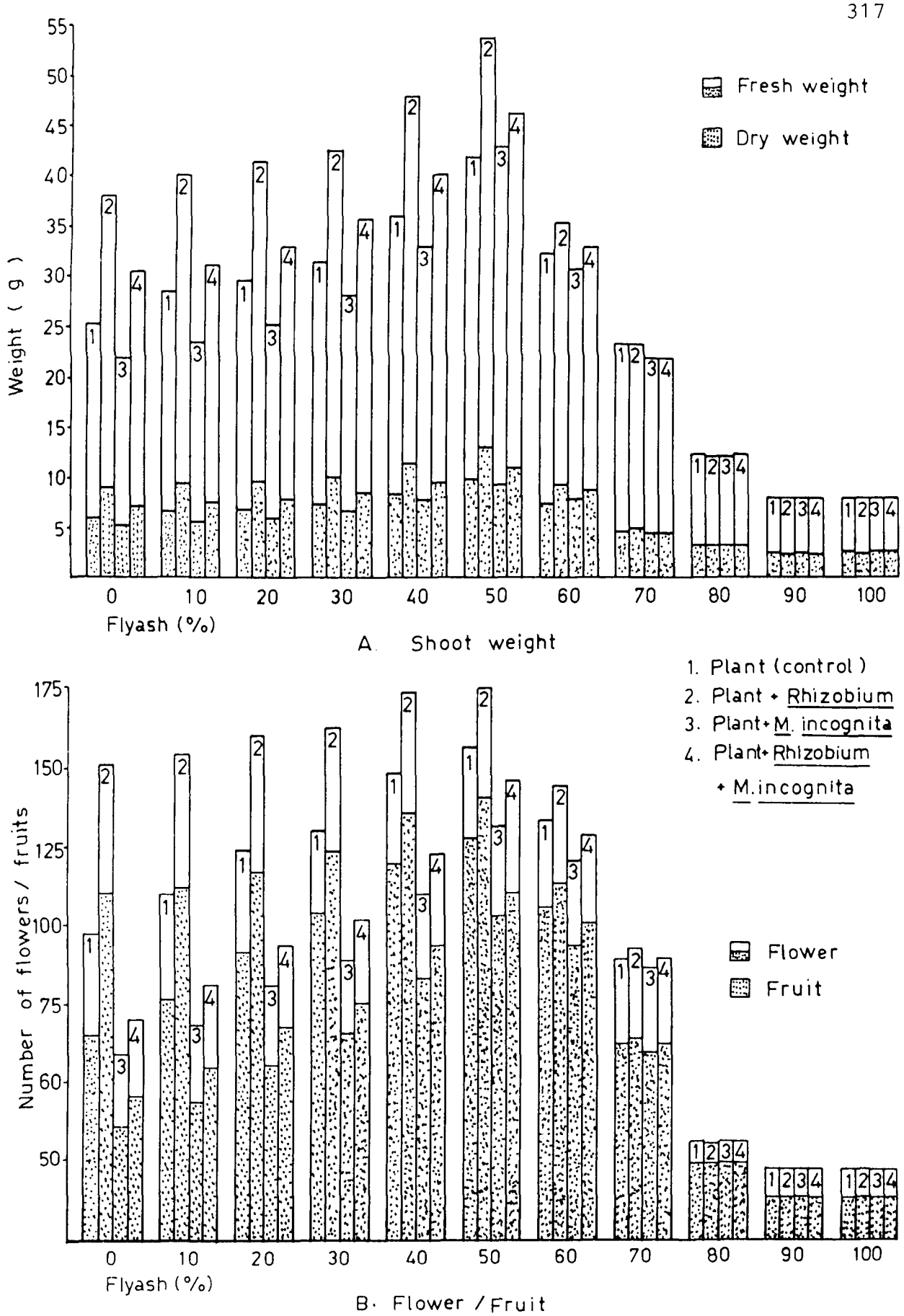

Fig.3. Interactive effects of flyash amended soil, M. incognita and root nodule bacteria on some parameters of chick-pea.

Table 14. Interactive effects of flyash amended soil, root-knot nematodes and root nodule bacteria on root galling, eggmass production and root noculation on chick-pea.

Flyash (%)		Gall/Eggmass P	P+Rh	P+Mi	P+Rh+Mi	P+Mj	P+Rh+Mj	L.S.D. 0.01	L.S.D. 0.05		Nodule P+Rh	P+Rh+Mi	P+Rh+Mj	L.S.D. 0.01	L.S.D. 0.05
00 (Control)	G	-	-	176.2	125.6	83.4	52.2	8.05	5.74	T	140.4	100.2 (15.2)	125.4 (11.2)	18.46 (3.17)	12.69 (1.91)
	E	-	-	108.6	86.4	48.6	33.8	7.40	5.28	F	120.6	70.8	100.6	13.30	9.14
10	G	-	-	183.4	137.2	87.6	59.2	7.88	5.62	T	137.6	100.4 (18.2)	115.4 (11.4)	8.47 (2.02)	5.82 (1.22)
	E	-	-	84.2	71.4	42.4	33.2	6.55	4.67	F	114.4	70.4	82.0	8.69	5.97
20	G	-	-	195.6	160.8	95.4	65.4	8.23	5.87	T	118.2	87.7 (20.4)	103.2 (14.2)	7.80 (1.96)	5.37 (1.18)
	E	-	-	66.4	54.2	32.8	31.6	6.38	4.55	F	,94.4	60.6	76.2	6.58	4.52
30	G	-	-	203.0	165.4	98.0	69.8	8.75	6.24	T	93.0	74.2 (25.4)	90.4 (17.2)	5.56 (2.17)	3.82 (1.31)
	E	-	-	47.6	11.2	27.2	24.4	4.89	3.49	F	71.4	50.4	64.8	4.80	3.30
40	G	-	-	210.4	168.2	105.6	75.2	9.10	6.49	T	71.8	56.8 (27.4)	71.0 (20.4)	5.08 (2.12)	3.49 (1.28)
	E	-	-	34.4	23.8	22.4	15.4	3.74	2.67	F	56.6	36.2	48.4	4.52	3.11
50	G	-	-	228.8	175.4	112.2	80.4	8.93	6.37	T	56.2	43.6 (21.2)	52.8 (18.4)	4.28 (2.11)	2.94 (1.27)
	E	-	-	17.8	14.2	13.6	11.2	2.47	1.76	F	45.8	26.8	33.2	4.54	3.12
60	G	-	-	104.2	97.4	72.4	60.2	9.14	6.52	T	32.4	21.2 (10.6)	26.2 (11.4)	2.66 (0.70)	1.83 (0.42)
	E	-	-	11.2	9.6	10.2	9.4	0.81	0.58	F	27.2	12.4	16.6	3.24	2.23
70	G	-	-	38.0	36.2	32.4	29.8	5.12	3.65	T	13.4	10.2 (0.0)	12.4 (0.0)	1.21 (0.00)	0.83 (0.00)
	E	-	-	0.0	0.0	0.0	0.0	0.00	0.00	F	6.2	6.4	6.2	0.54	0.37
80	G	-	-	10.4	10.2	14.2	14.4	1.04	0.74	T	0.0	0.0 (0.0)	0.0 (0.0)	0.00 (0.00)	0.00 (0.00)
	E	-	-	0.0	0.0	0.0	0.0	0.00	0.00	F	0.0	0.0	0.0	0.00	0.00
90	G	-	-	0.0	0.0	0.0	0.0	0.00	0.00	T	0.0	0.0 (0.0)	0.0 (0.0)	0.00 (0.00)	0.00 (0.00)
	E	-	-	0.0	0.0	0.0	0.0	0.00	0.00	F	0.0	0.0	0.0	0.00	0.00
100	G	-	-	0.0	0.0	0.0	0.0	0.00	0.00	T	0.0	0.0 (0.0)	0.0 (0.0)	0.00 (0.00)	0.00 (0.00)
	E	-	-	0.0	0.0	0.0	0.0	0.00	0.00	F	0.0	0.0	0.0	0.00	0.00
L.S.D.															
0.01	G	-	-	6.58	6.37	5.20	4.94			T	8.58	7.33 (3.28)	7.16 (2.18)		
	E	-	-	4.67	4.24	3.00	3.09			F	6.94	4.67	5.38		
0.05	G	-	-	4.92	4.76	3.89	3.69			T	6.42	5.48 (2.45)	5.35 (1.63)		
	E	-	-	3.49	3.17	2.24	2.31			F	5.19	3.49	4.02		

G = Gall, E = Eggmass

T = Total, F = Functional. (No. of infected nodules with root-knot nematodes are given in parenthesis)

Each value is mean of five replicates.

The root nodulation was suppressed by both M. incognita and M. javanica. M. incognita was more suppressive. Flyash also suppressed root nodulation. It exhibited stepwise decrease upto 70% flyash level. No nodulation occurred in 80-100% flyash levels. The number of functional nodules also declined with the increasing level of flyash. The decrease in the number of nodules caused by the root-knot nematodes was less in the flyash amended soil and was related with the level of flyash. In control soil, root nodule infection by root-knot nematode was greater in M. incognita inoculated plants than in plants inoculated with M. javanica. The number of infected nodules by both M. incognita and M. javanica increased upto 40% flyash level but gradually decreased at 50% and 60% flyash levels. At 60% flyash level, the number of nodules infected with M. incognita decreased but the number of nodules infected with M. javanica was greater than in unpolluted (control) soil and was even greater than the number of nodules infected with M. incognita at the same level of flyash. The infection of root nodules was completely checked at 70% and higher levels of flyash (Table 14).

Leaf pigments and seed proteins

The leaf pigments (chlorophyll a, chlorophyll b and total chlorophyll) and seed proteins (soluble and insoluble) were affected by Rhizobium, M. incognita and M.

Table 15. Interactive effects of flyash amended soil, root-knot nematodes and root nodule bacteria on chlorophyll content of leaves of chick-pea.

Treatment		Chlorophyll (mg/g)											L.S.D.	
		00(Control)	10	20	30	40	50	60	70	80	90	100	0.01	0.05
P (Control)	A	0.621	0.674	0.712	0.786	0.917	1.153	1.047	0.679	0.532	0.449	0.432	0.074	0.055
	B	0.571	0.611	0.645	0.714	0.834	1.051	0.954	0.620	0.485	0.408	0.403	0.084	0.063
	T	1.313	1.425	1.504	1.661	1.941	2.436	2.213	1.436	1.125	0.948	0.936	0.123	0.092
P+Rh	A	0.943	0.959	0.988	1.093	1.253	1.496	1.275	0.733	0.535	0.447	0.447	0.100	0.075
	B	0.878	0.874	0.909	0.996	1.143	1.366	1.164	0.680	0.488	0.406	0.369	0.098	0.073
	T	1.901	2.029	2.112	2.309	2.652	3.161	2.695	1.549	1.131	0.944	0.938	0.158	0.118
P+Mi	A	0.447	0.493	0.524	0.587	0.702	0.917	0.874	0.629	0.533	0.451	0.445	0.095	0.071
	B	0.412	0.446	0.473	0.531	0.637	0.834	0.795	0.574	0.486	0.410	0.371	0.100	0.075
	T	0.945	1.042	1.107	1.240	1.486	1.937	1.848	1.330	1.128	0.952	0.940	0.166	0.124
P+Rh+Mi	A	0.612	0.662	0.699	0.775	0.911	1.153	1.021	0.667	0.532	0.448	0.442	0.096	0.072
	B	0.559	0.598	0.633	0.703	0.828	1.051	0.930	0.609	0.485	0.407	0.403	0.091	0.068
	T	1.285	1.399	1.477	1.637	1.926	2.466	2.158	1.409	1.125	0.946	0.936	0.136	0.102
P+Mj	A	0.520	0.568	0.611	0.679	0.806	1.039	0.961	0.618	0.531	0.449	0.443	0.087	0.065
	B	0.479	0.513	0.552	0.616	0.732	0.947	0.875	0.564	0.484	0.408	0.369	0.104	0.078
	T	1.094	1.201	1.287	1.435	1.705	2.197	2.032	1.360	1.123	0.948	0.938	0.173	0.129
P+Rh+Mj	A	0.729	0.786	0.837	0.920	1.076	1.328	1.152	0.661	0.533	0.448	0.433	0.084	0.063
	B	0.660	0.714	0.760	0.837	0.980	1.212	1.050	0.603	0.486	0.407	0.403	0.080	0.060
	T	1.539	1.661	1.768	1.944	2.278	2.806	2.434	1.397	1.128	0.946	0.936	0.147	0.110
L.S.D.														
0.01	A	0.060	0.067	0.075	0.078	0.090	0.102	0.105	0.070	0.040	0.033	0.033		
	B	0.057	0.071	0.072	0.085	0.086	0.106	0.104	0.063	0.037	0.037	0.029		
	T	0.106	0.112	0.131	0.134	0.146	0.169	0.170	0.130	0.056	0.053	0.052		
0.05	A	0.044	0.0049	0.055	0.057	0.066	0.075	0.077	0.051	0.029	0.024	0.024		
	B	0.042	0.052	0.053	0.062	0.063	0.078	0.076	0.046	0.027	0.027	0.021		
	T	0.078	0.082	0.096	0.098	0.107	0.124	0.125	0.095	0.041	0.039	0.038		

A = Chl.a, B = Chl.b, T = Total chl.

Each value is mean of five replicates.

Table 16. Interactive effects of flyash amended soil, root-knot nematodes and root nodule bacteria on protein content of seeds of chick-pea.

Treatment		Protein(%)											L.S.D.	
		00(Control)	10	20	30	40	50	60	70	80	90	100	0.01	0.05
P (Control)	S	11.30	11.44	11.52	11.56	11.68	11.72	11.60	11.40	10.28	10.02	9.98	0.63	0.47
	I	14.36	14.66	15.18	15.62	16.08	16.38	15.98	14.02	13.48	12.66	12.62	0.84	0.63
	T	25.66	26.10	26.70	27.18	27.76	28.10	27.58	25.42	23.76	22.68	22.60	1.31	0.98
P+Rh	S	12.34	12.46	12.54	12.52	12.64	12.62	11.96	11.32	10.46	10.06	9.96	0.62	0.46
	I	15.62	15.72	16.02	16.12	16.36	17.46	16.24	14.40	13.28	12.66	12.64	0.99	0.74
	T	27.96	28.18	28.56	28.64	29.00	29.08	28.20	25.72	23.74	22.72	22.60	1.18	0.88
P+Mi	S	10.94	11.12	11.20	11.28	11.46	11.58	11.50	11.16	10.44	10.04	9.98	0.48	0.36
	I	13.96	14.22	14.74	15.10	15.78	16.12	15.82	14.18	13.30	12.66	12.60	0.79	0.59
	T	24.90	25.34	25.94	26.38	27.24	27.70	27.32	25.34	23.74	22.70	22.58	1.02	0.76
P+Rh+Mi	S	11.40	11.58	11.66	11.72	11.88	12.02	11.76	11.30	10.48	10.02	9.98	0.51	0.38
	I	14.38	14.64	15.12	15.46	16.14	16.38	15.98	14.34	13.30	12.64	12.64	0.55	0.41
	T	25.78	26.22	26.78	27.18	28.02	28.40	27.74	25.64	23.78	22.66	22.62	0.92	0.69
P+Mj	S	11.10	11.24	11.32	11.48	11.56	11.68	11.56	11.14	10.46	10.04	9.96	0.52	0.39
	I	14.06	14.36	14.90	15.30	15.92	16.24	15.94	14.14	13.30	10.66	12.62	0.75	0.56
	T	25.16	25.60	26.22	26.78	27.48	27.92	27.50	25.28	23.76	22.70	22.58	1.15	0.86
P+Rh+Mj	S	11.68	11.86	11.98	12.12	12.22	12.28	11.78	11.28	10.44	10.02	9.98	0.55	0.41
	I	14.72	15.02	15.52	15.86	16.30	16.42	16.26	14.32	13.30	10.64	12.62	0.76	0.57
	T	26.40	26.88	27.50	27.98	28.52	28.70	28.04	25.60	27.74	22.66	22.60	1.23	0.92
L.S.D.														
0.01	S	0.65	0.67	0.65	0.49	0.44	0.48	0.34	0.25	0.20	0.19	0.16		
	I	0.63	0.71	0.67	0.57	0.42	0.46	0.37	0.31	0.23	0.23	0.19		
	T	0.97	1.02	1.04	0.86	0.79	0.78	0.65	0.44	0.33	0.27	0.31		
0.05	S	0.48	0.49	0.48	0.36	0.32	0.35	0.25	0.18	0.15	0.14	0.12		
	I	0.46	0.52	0.49	0.42	0.31	0.34	0.27	0.23	0.17	0.17	0.14		
	T	0.71	0.75	0.76	0.63	0.58	0.[illegible]	0.48	0.32	0.24	0.21	0.23		

S = Soluble, I = Insoluble, T = Total

Each value is mean of five replicates.

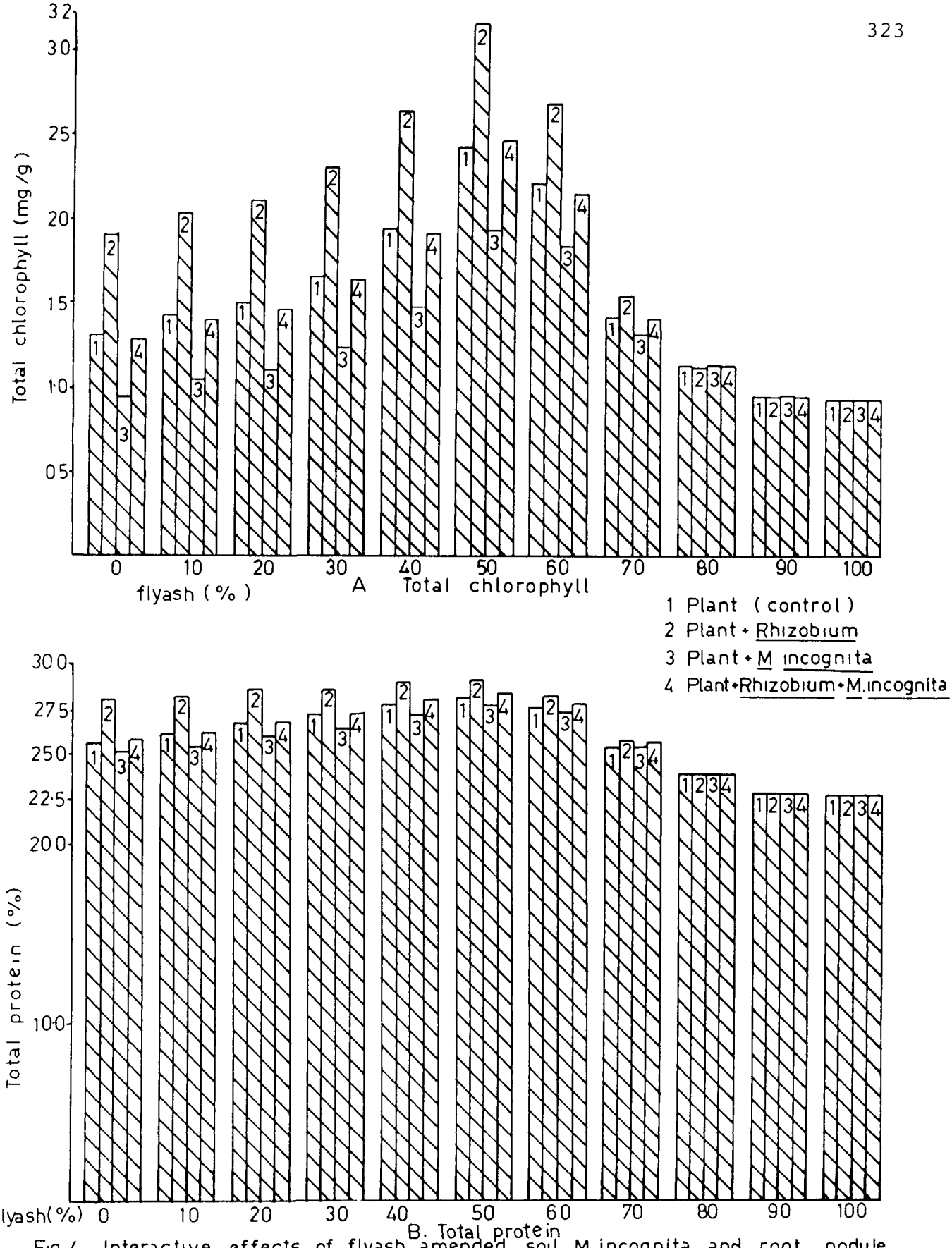

Fig 4 Interactive effects of flyash amended soil, M incognita and root nodule bacteria on some parameters of chick-pea

javanica alone and in combination in the same way as described in Part A of this section. The increasing level of flyash in the soil caused step-wise increase in the chlorophyll and protein contents. These parameters increased upto 50% of flyash level. From 60% level, the increase in chlorophyll and protein contents showed an abrupt decline. At 80%, chlorophyll content decreased significantly in comparison to control soil. The total protein and insoluble protein contents of seeds also decreased when compared with control. Further, till 100% flyash level, the chlorophyll and protein contents gradually decreased. The individual and combined effects of Rhizobium and M. incognita and M. javanica on the chlorophyll and protein contents were reduced gradually with the increasing level of flyash in the soil. At the 70%, the suppressive effect of M. javanica was greater than M. incognita either alone or in combination, with Rhizobium. From 80% onward, the chlorophyll and protein contents in the differet treatments of Meloidogyne and Rhizobium were same (Tables 15 and 16, Figs. 4A and 4 B).

Leaf epidermal characters

Rhizobium and M. incognita and M. javanica individually or concomitantly in the unpolluted soil affected all the leaf epidermal characters considered in the study on the same pattern as obtained in Part A of this section. The number of stomata and trichome-hydathodes, size of

Table 17. Interactive effects of flyash amended soil, root-knot nematodes and root nodule bacteria on the number of stomata on leaves of chick-pea.

Flyash (%)		Number of stomata/cm^2						L.S.D.	
		P	P+Rh	P+Mi	P+Rh+Mi	P+Mj	P+Rh+Mj	0.01	0.05
00 (Control)	L	24902.12	30240.45	23140.26	25916.74	23810.36	27847.42	678.46	497.46
	U	13884.45	17160.17	12121.02	14344.75	12879.11	15352.25	520.92	381.95
10	L	25241.92	30113.61	23480.46	26110.71	24108.81	27966.22	661.99	485.38
	U	14161.68	17135.63	12816.02	14635.87	13235.22	15683.73	538.46	394.81
20	L	25866.72	30522.73	24288.00	26716.80	24824.11	28299.48	599.77	439.76
	U	14786.46	17743.75	13791.17	15334.11	14082.34	16546.75	549.02	402.55
30	L	26741.44	31020.07	25347.34	27375.12	25762.47	28982.78	683.59	501.22
	U	15272.40	18021.43	14273.27	15729.15	14614.74	16834.18	512.36	375.67
40	L	27991.04	31769.83	26914.46	28394.76	26123.10	29971.03	646.22	473.82
	U	15827.76	18201.92	14931.85	16126.46	15219.02	17197.47	561.62	411.79
50	L	28490.88	31339.97	27714.86	28546.31	27795.98	**29463.74**	581.52	426.38
	U	16105.44	17877.04	15486.05	16260.28	15789.65	17052.82	550.85	403.89
60	L	**26491.52**	27816.10	26100.02	26491.52	26229.23	27016.11	508.05	372.51
	U	14994.72	15894.40	14700.70	15141.73	14920.12	15666.12	502.42	368.38
70	L	25491.84	26001.68	24048.91	24361.53	23713.34	23950.45	421.77	309.25
	U	14439.36	14800.34	13596.38	13868.31	13394.58	13582.11	432.40	317.04
80	L	23577.36	23648.46	23679.52	23458.31	23548.21	23496.82	292.33	214.34
	U	13350.27	13386.52	13312.11	13329.92	13375.24	13401.18	334.64	245.37
90	L	22928.44	22848.25	22882.71	23036.59	22941.68	23057.82	213.76	156.73
	U	12975.70	12965.46	12955.63	12996.42	12962.76	12973.39	203.95	149.54
100	L	22874.36	22839.27	22944.72	22858.56	22892.68	22841.06	223.52	163.89
	U	12932.76	13124.42	12951.39	12992.67	13048.42	13981.84	196.15	143.82
L.S.D.									
0.01	L	510.72	458.42	570.49	525.37	503.71	538.75		
	U	551.54	545.03	508.58	527.50	556.88	534.44		
0.05	L	381.72	342.63	426.39	392.67	376.48	402.67		
	U	412.23	407.36	380.12	394.26	416.22	399.45		

L = Lower surface, U = Upper surface,

Each value is mean of five replicates.

Table 18. Interactive effects of flyash amended soil, root-knot nematodes and root nodule bacteria on the size of stomata and stomatal aperture on leaves of chick-pea.

Fly ash (%)		Size of stomatal (μm^2)						L.S.D.		Size of stomatal aperture (μm^2)						L.S.D.	
		P	P+Rh	P+Mi	P+Rh+Mi	P+Mj	P+Rh+Mj	0.01	0.05	P	P+Rh	P+Mi	P+Rh+Mi	P+Mj	P+Rh+Mj	0.01	0.05
00	L	396.33	459.74	360.61	402.27	376.89	429.65	29.42	21.57	86.44	96.81	75.17	81.18	78.58	86.58	7.80	5.72
(Control)	U	368.95	446.57	340.94	387.26	352.69	410.12	31.48	23.08	62.50	71.88	53.65	59.55	55.31	61.95	6.64	4.87
10	L	398.31	456.07	368.12	404.94	376.83	425.82	33.26	24.39	87.74	97.39	76.96	82.74	79.76	87.91	7.72	5.66
	U	384.13	448.28	348.57	390.40	359.67	412.90	30.67	22.49	64.06	72.90	55.70	61.55	57.20	63.49	6.91	5.07
20	L	402.27	450.55	375.95	406.78	383.11	422.19	41.52	30.44	89.90	97.99	80.63	85.87	82.86	90.31	7.86	5.76
	U	393.59	448.69	362.76	390.03	369.57	415.76	32.36	23.73	66.56	73.88	59.16	64.49	60.40	66.02	6.96	5.10
30	L	412.18	457.52	386.66	413.73	394.81	433.10	38.58	28.29	91.63	99.23	83.15	87.72	85.24	92.06	8.22	6.03
	U	404.94	457.58	377.39	411.36	384.56	426.86	32.58	23.89	67.00	73.83	66.22	64.78	61.36	66.33	6.94	5.09
40	L	428.83	471.71	404.56	428.83	412.34	450.27	43.89	32.18	93.16	100.64	86.20	90.08	88.06	94.23	7.94	5.82
	U	421.97	472.61	398.08	427.94	405.74	443.07	33.10	24.27	67.81	71.19	61.48	65.47	62.79	67.18	6.66	4.88
50	L	437.94	468.60	421.10	440.05	427.26	457.17	40.32	29.56	95.95	100.27	90.25	93.23	91.82	95.23	7.79	5.71
	U	431.43	470.26	414.84	437.65	420.91	450.37	38.45	28.19	69.69	74.22	65.13	68.06	65.75	69.03	6.10	4.47
60	L	416.15	432.79	407.99	418.19	414.08	430.64	29.06	21.31	91.63	93.38	88.96	90.30	89.83	91.63	6.38	4.68
	U	404.94	429.29	395.06	410.24	400.93	416.92	33.86	24.83	66.56	68.89	64.00	65.28	64.94	66.56	5.13	3.78
70	L	400.29	405.09	400.62	407.49	399.09	405.48	25.56	18.74	87.30	87.38	87.32	87.15	87.25	87.35	4.79	3.51
	U	389.80	394.48	387.86	394.84	387.45	392.90	29.05	21.30	63.75	63.87	63.84	63.71	63.68	63.74	4.58	3.36
80	L	384.79	382.37	379.42	382.59	391.43	381.38	21.24	15.57	83.92	82.16	85.29	84.88	81.39	84.68	4.35	3.19
	U	371.03	374.22	375.31	371.62	369.35	372.27	22.95	16.83	60.68	60.29	61.45	59.76	60.85	61.21	4.42	3.24
90	L	366.97	369.82	364.45	361.28	359.41	364.56	18.13	13.29	80.79	82.27	83.05	81.14	79.47	81.89	3.34	2.45
	U	357.03	356.32	353.16	362.45	354.82	359.59	18.34	13.45	58.96	59.41	61.23	60.82	59.34	60.76	4.35	3.19
100	L	361.31	368.58	367.62	362.68	368.72	366.41	19.33	14.17	80.74	81.76	82.42	79.34	81.44	79.86	3.53	2.59
	U	358.20	362.74	359.36	356.49	361.24	354.32	18.17	13.32	58.97	59.16	60.36	57.29	59.44	58.52	4.23	3.10
L.S.D.																	
0.01	L	18.05	15.68	16.83	11.99	13.98	11.31			5.14	4.23	3.96	4.33	4.54	4.09		
	U	19.09	18.68	18.84	17.61	16.62	17.71			3.96	4.28	4.20	3.84	4.00	3.91		
0.05	L	13.49	11.72	12.58	8.69	10.45	8.45			3.84	3.16	2.96	3.24	3.39	3.06		
	U	14.27	13.96	14.08	13.16	12.42	13.24			2.96	3.20	3.14	2.87	2.99	2.92		

L = Lower surface, U = Upper surface

Each value is mean of five replicates.

Table 19. Interactive effects of flyash amended soil, root-knot nematodes and root nodule bacteria on the number and length of trichome-hydathodes on leaves of chick-pea.

Fly ash (%)		No. of trichome-hydathodes (μm)						L.S.D.		Length of trichome-hydathodes (μm)						L.S.D.	
		P	P+Rh	P+Mi	P+Rh+Mi	P+Mj	P+Rh+Mj	0.01	0.05	P	P+Rh	P+Mi	P+Rh+Mi	P+Mj	P+Rh+Mj	0.01	0.05
00 (Control)	L	651.39	1097.02	497.24	721.03	552.03	866.69	97.45	71.45	424.00	562.22	375.22	446.51	388.90	482.24	40.53	29.72
	U	411.40	1028.16	304.74	624.72	340.04	782.14	90.27	66.19	404.13	545.76	351.42	428.73	364.08	460.56	47.58	34.89
10	L	670.93	1113.75	520.10	744.78	573.44	883.10	96.74	70.93	430.36	561.62	382.54	451.40	396.65	487.88	44.72	32.79
	U	427.86	748.75	320.01	473.62	357.15	571.43	94.54	69.32	414.23	553.00	363.36	437.85	375.55	469.44	46.08	33.79
20	L	693.73	1109.97	554.98	776.98	600.63	900.95	99.89	73.24	439.26	562.26	393.96	456.79	408.61	492.38	41.56	30.47
	U	448.43	748.87	342.31	492.93	381.64	591.55	92.62	67.91	424.34	551.64	378.87	448.59	389.30	471.06	49.48	36.28
30	L	703.50	1090.43	569.64	783.25	622.57	908.95	99.97	73.30	440.96	551.20	402.70	458.28	414.05	490.65	45.53	33.38
	U	454.60	695.53	357.95	501.13	398.77	598.16	94.72	69.45	432.42	547.01	391.33	455.51	401.88	476.22	50.53	37.05
40	L	719.79	1067.44	594.62	799.76	653.17	927.50	98.81	72.45	443.50	541.07	412.56	457.94	420.38	487.64	42.57	31.21
	U	467.35	733.74	379.96	516.74	422.94	606.92	96.08	70.24	446.56	547.04	408.56	457.59	420.09	488.57	50.35	36.92
50	L	736.07	1030.50	640.06	800.08	687.92	887.41	98.52	72.89	453.68	517.20	432.08	466.64	438.34	490.94	36.58	26.82
	U	477.22	677.66	411.40	517.25	446.00	588.72	91.80	67.31	456.67	525.17	426.79	460.94	439.11	487.41	42.61	31.24
60	L	696.99	836.38	630.44	716.17	670.18	777.41	78.82	57.83	440.96	471.83	428.12	446.24	434.44	460.51	29.39	21.55
	U	444.31	555.39	403.92	452.39	427.22	512.67	72.09	52.86	432.42	467.01	415.79	430.34	423.94	449.38	36.11	26.48
70	L	670.93	711.19	652.66	682.03	648.24	674.17	53.86	39.49	428.24	443.23	423.16	433.74	417.80	426.15	25.63	18.79
	U	427.86	456.10	416.61	439.53	414.59	434.49	45.93	33.68	416.25	432.90	408.89	421.16	408.09	418.29	29.58	21.69
80	L	626.34	628.53	626.42	630.28	629.67	625.35	34.34	25.18	403.81	401.76	403.81	407.42	400.59	406.51	22.89	16.78
	U	399.42	392.62	395.53	404.36	401.42	397.82	27.93	20.48	388.59	384.26	386.73	387.66	389.84	385.72	24.02	17.61
90	L	586.84	581.55	584.89	589.72	586.55	590.37	26.91	19.73	385.45	389.67	390.39	384.41	390.28	383.36	17.13	12.56
	U	377.43	378.42	381.71	374.92	377.46	382.19	23.10	16.94	374.19	377.42	378.26	372.72	378.83	374.43	20.85	15.29
100	L	585.92	587.29	586.32	582.61	589.73	583.52	26.68	19.56	382.29	386.07	381.39	390.45	374.76	386.25	16.63	12.19
	U	377.59	380.18	374.45	379.37	374.48	376.38	23.99	17.59	373.41	374.32	379.86	371.73	376.59	379.38	20.29	14.88
L.S.D.																	
0.01	L	32.37	39.12	41.16	32.55	35.58	33.19			12.54	15.37	18.34	13.94	13.22	14.40		
	U	28.62	46.07	26.57	30.44	33.49	31.16			21.76	13.79	18.62	15.27	19.69	20.97		
0.05	L	24.19	29.24	30.76	24.33	26.59	24.81			9.37	11.49	13.71	10.42	9.88	10.76		
	U	21.39	34.43	19.86	22.75	25.03	23.29			16.26	10.31	13.92	11.41	14.72	15.67		

L = Lower surface, U = Upper surface

Each value is mean of five replicates.

stomata and stomatal aperture and length of trichome-hydathodes gradually increased upto 50% flyash level. The increase in these parameters was reduced at 60% flyash level. Further, reduction occurred at 70% level. The number of stomata and trichome-hydathodes, size of stomata and stomatal aperture and length of trichome-hydathodes decreased at 80% flyash level and the decrease was greater at 90% and 100% flyash levels. The individual and combined effects of Rhizobium and M. incognita and M. javanica on leaf epidermal characters were reduced upto 70% flyash level and became negligible at 80%. The effect of flyash from 80% and onward on leaf epidermal characters in the various treatments of Rhizobium and Meloidogyne spp. remained same. At 70% flyash level, the suppressive effect of M. javanica was greater than M. incognita (Tables 17, 18 and 19).

The number and length of trichomes gradually declined in flyash amended soils upto 50%. But the decrease in trichome parameters was less at 60% flyash. The parameters of trichomes showed an increase at 80% flyash level. The number and length of trichomes increased further at 90% flyash level and became constant onwards. The individual and combined effects of Rhizobium and root-knot nematodes on trichome parameters gradually declined with the increasing level of flyash in soil. At 70% flyash, the effect of M. javanica was greater than M. incognita. From

Table 20. Interactive effect of flyash amended soil, root-knot nematodes and root-nodule bacteria on the number and length of trichomes on leaves of chick-pea.

Fly ash (%)		No. of trichomes (μm) P	P+Rh	P+Mi	P+Rh+Mi	P+Mj	P+Rh+Mj	L.S.D. 0.01	L.S.D. 0.05	Length of trichomes (μm) P	P+Rh	P+Mi	P+Rh+Mi	P+Mj	P+Rh+Mj	L.S.D. 0.01	L.S.D. 0.05
00 (Control)	L	3039.57	1885.59	3556.30	2694.17	3373.92	2249.28	173.80	127.43	331.25	238.65	371.00	304.10	361.06	284.29	31.04	22.76
	U	1651.24	988.62	2030.73	1430.09	1915.16	1212.13	171.41	125.68	321.75	238.11	380.93	320.82	367.68	285.02	37.38	27.41
10	L	2965.43	1888.81	3431.01	2639.23	3267.90	2301.34	176.43	129.36	326.35	239.09	364.21	300.50	354.09	283.27	29.31	21.49
	U	1587.50	997.99	1928.81	1387.63	1825.62	1185.47	175.01	128.32	318.78	228.52	363.41	311.94	352.89	277.87	32.95	24.16
20	L	2854.06	1902.70	3225.09	2580.07	3110.93	2238.08	175.19	128.45	320.05	240.64	355.26	296.05	345.01	283.96	31.15	22.84
	U	1521.66	981.71	1810.78	1351.32	1719.48	1169.71	176.86	129.68	308.25	228.34	345.24	302.31	339.99	276.42	32.17	23.59
30	L	2779.86	1914.39	3097.86	2539.23	3006.26	2226.86	177.58	130.17	313.98	241.52	342.24	292.51	337.21	282.19	32.21	23.62
	U	1454.63	963.33	1720.83	1308.61	1621.91	1134.20	176.47	129.39	304.80	230.91	338.94	299.95	334.67	276.59	34.36	25.19
40	L	2620.32	1885.12	2882.35	2442.67	2816.84	2166.80	181.28	132.92	308.14	244.56	329.71	289.22	329.71	281.08	31.93	23.41
	U	1399.15	964.93	1644.00	1284.38	1546.06	1128.51	179.70	131.76	299.77	232.38	331.25	297.08	327.65	276.26	36.32	26.63
50	L	2575.91	2028.27	2756.22	2335.78	2704.71	2181.21	178.76	131.07	302.51	256.37	317.64	286.16	314.61	275.97	28.72	21.06
	U	1364.46	1049.59	1541.84	1306.64	1459.97	1167.98	180.27	132.18	293.05	244.21	313.56	282.49	310.63	270.12	36.22	26.56
60	L	2814.42	2490.63	2926.99	2761.32	2870.71	2609.73	174.06	127.62	318.51	294.92	328.07	312.44	324.88	303.63	25.00	18.33
	U	1501.91	1293.89	1622.06	1515.95	1561.99	1394.63	169.96	124.62	308.25	280.23	320.58	305.31	317.50	293.98	31.01	22.74
70	L	2951.04	2810.51	3001.21	2880.24	3010.06	2902.66	149.27	109.45	288.04	279.65	290.92	283.01	293.22	286.91	22.33	16.37
	U	1587.73	1497.86	1619.48	1557.20	1627.42	1552.88	154.78	113.49	318.78	308.02	323.56	314.14	326.11	318.16	25.35	18.59
80	L	3085.16	3093.39	3090.72	3082.68	3086.53	3091.92	133.40	97.81	337.88	332.59	344.38	336.62	342.47	330.32	22.69	16.64
	U	1684.02	1681.42	1689.31	1693.57	1682.78	1679.45	128.64	94.32	336.55	335.41	343.26	338.92	332.29	335.47	22.82	16.73
90	L	3221.94	3232.39	3226.27	3225.31	3219.53	3224.86	140.85	103.27	351.13	359.52	354.64	359.39	352.22	358.54	23.21	17.02
	U	1733.55	1738.87	1734.39	1740.84	1735.83	1737.44	133.38	97.80	346.36	341.69	349.39	351.28	353.79	345.88	23.38	17.14
100	L	3229.39	3233.21	3222.46	3217.72	3225.32	3231.26	140.15	102.76	356.29	355.42	352.91	350.08	355.53	357.77	23.14	16.97
	U	1735.84	1731.75	1739.24	1742.89	1730.42	1738.81	133.84	98.13	352.68	345.31	343.62	350.19	344.87	352.48	23.66	17.35
L.S.D.																	
0.01	L	158.85	182.52	166.82	174.66	173.43	178.74			17.03	12.64	14.29	13.13	12.87	9.97		
	U	129.23	143.48	148.99	114.25	151.24	116.96			15.32	11.56	21.37	17.6	15.09	17.25		
0.05	L	118.73	136.42	124.68	130.54	129.62	133.59			12.73	9.45	10.68	9.81	9.62	7.45		
	U	96.59	107.24	111.36	55.39	113.04	87.42			11.45	8.64	15.97	13.17	11.28	12.89		

L = Lower surface, U = Upper surface

Each value is mean of five replicates.

80 to 100%, the effects of Rhizobium and Meloidogyne spp. were eliminated completely (Table 20).

LENTIL, Lens culinaris Medic.

Plant growth and yield

Plant growth and yield parameters of lentil were also influenced by the artificial amendment of soil with flyash. These parameters gradually increased with the increasing level of flyash from 10% to 50-60%. But after 60% i.e. 70% onward the increase in the growth and yield parameters gradually declined upto 90%. The plant growth and yield observed in 90 and 100% flyash levels were, however, similar. The effects of Rhizobium, M, incognita and javanica individually or when Rhizobium was combined with M.incognita or M. javanica in unpolluted control soil were similar as observed in the Part A of this section. Rhizobium improved plant growth and yield of lentil. Both the species of Meloidogyne caused reductions; M. incognita being more damaging. These damaging effects of Meloidogyne spp. were reduced in the presence of Rhizobium. These effects were gradually suppressed upto 70% flyash level (Tables 21 and 22, Figs. 5 A and 5 B).

Root-knot disease and root nodulation

M. incognita was more pathogenic to lentil than M. javanica. Root galling and eggmass production were

Table 21. Interactive effects of flyash amended soil, root-knot nematodes and root nodule bacteria on plant length and fresh weight of lentil.

Fly ash (%)		Length (cm)						L.S.D.		Fresh weight (g)						L.S.D.	
		P	P+Rh	P+Mi	P+Rh+Mi	P+Mj	P+Rh+Mj	0.01	0.05	P	P+Rh	P+Mi	P+Rh+Mi	P+Mj	P+Rh+Mj	0.01	0.05
00 (Control)	S	31.4	38.7	24.2	27.5	26.8	32.4	2.92	2.14	16.5	23.75	12.95	16.40	14.50	19.85	1.83	1.34
	R	17.2	21.5	13.3	15.4	16.5	19.7	1.62	1.19	12.15	19.60	8.55	11.35	10.45	14.65	1.65	1.19
10	S	32.8	39.3	25.6	29.8	27.6	32.4	2.84	2.08	17.35	24.55	13.60	16.75	15.40	20.85	1.77	1.30
	R	18.4	21.9	14.4	16.3	17.2	20.0	1.73	1.27	13.00	20.15	9.15	11.90	11.05	14.95	1.58	1.16
20	S	33.1	39.5	27.3	30.2	28.6	32.5	3.07	2.25	19.00	26.45	15.2	18.45	17.25	22.80	1.75	1.29
	R	20.2	23.8	16.5	18.7	18.6	21.3	1.79	1.31	14.80	22.35	10.75	13.85	12.75	17.10	1.62	1.19
30	S	35.4	41.6	29.4	32.5	31.6	35.8	3.36	2.46	22.60	30.35	18.60	22.15	20.85	26.90	1.91	1.40
	R	21.8	24.6	18.2	20.1	19.2	22.3	1.99	1.46	17.15	25.30	12.95	16.45	14.85	19.45	1.76	1.29
40	S	36.2	42.6	31.5	34.8	33.8	37.3	3.25	2.38	26.25	34.10	22.65	26.00	24.30	30.10	2.07	1.52
	R	23.9	26.1	20.2	22.4	23.3	24.5	2.09	1.53	19.45	27.90	15.40	19.10	17.15	21.80	1.81	1.33
50	S	38.3	43.8	35.2	38.1	36.6	40.3	2.96	2.16	29.55	36.85	26.30	29.95	28.15	33.05	1.90	1.39
	R	27.2	29.8	25.1	27.4	25.6	27.2	1.83	1.34	21.05	29.10	17.50	21.25	19.10	23.50	1.73	1.27
60	S	38.2	43.4	36.5	37.8	37.1	40.6	2.52	1.85	29.60	33.00	27.30	29.25	28.65	31.30	1.61	1.18
	R	27.4	25.5	25.8	27.4	26.3	26.8	1.66	1.22	22.20	25.50	19.15	22.25	20.35	24.00	1.61	1.18
70	S	31.8	33.5	31.2	32.4	31.4	32.8	1.90	1.39	21.05	21.90	20.55	21.10	20.75	21.45	1.60	1.17
	R	19.6	20.1	19.1	19.4	19.3	19.7	1.42	1.04	14.90	15.35	14.60	14.95	14.70	15.05	1.39	1.02
80	S	25.2	25.4	25.3	25.6	25.4	25.2	1.50	1.10	13.20	13.35	13.35	13.35	13.15	13.35	1.27	0.93
	R	11.7	11.9	11.7	11.5	11.2	11.5	1.16	0.85	9.75	9.80	9.65	9.75	9.90	9.80	1.02	0.75
90	S	16.10	16.7	16.4	16.4	16.3	16.9	0.57	0.42	10.45	10.40	10.55	10.35	10.65	10.35	0.70	0.51
	R	8.10	8.8	8.3	7.9	8.2	8.5	0.46	0.34	6.25	6.35	6.20	6.40	6.35	6.25	0.33	0.24
100	S	16.9	16.4	16.4	16.5	17.2	16.8	0.49	0.36	10.25	10.20	10.45	10.60	10.35	10.60	0.67	0.49
	R	8.3	8.7	8.4	8.1	8.2	8.3	0.50	0.37	6.35	6.30	6.25	6.45	6.30	6.45	0.30	0.22
L.S.D.																	
0.01	S	1.69	2.60	2.93	2.49	2.35	2.76			1.58	2.57	2.70	2.35	2.84	2.90		
	R	1.75	1.66	2.38	2.73	2.44	2.17			1.47	2.25	1.36	1.78	1.94	1.69		
0.05	S	1.26	1.94	2.19	1.86	1.76	2.06			1.18	1.92	2.02	1.76	2.12	2.17		
	R	1.31	1.24	1.78	2.04	1.82	1.62			1.10	1.68	1.02	1.33	1.45	1.26		

S = Shoot, R = Root

Each value is mean of five replicates.

Table 22. Interactive effects of flyash amended soil, root-knot nematodes and root-nodule bacteria on plant dry weight, flowering and fruiting of lentil.

Flyash (%)		Dry weight (g) P	P+Rh	P+Mi	P+Rh+Mi	P+Mj	P+Rh+Mj	L.S.D. 0.01	L.S.D. 0.05		Flower/Fruit P	P+Rh	P+Mi	P+Rh+Mi	P+Mj	P+Rh+Mj	L.S.D. 0.01	L.S.D. 0.05
00 (Control)	S	3.15	4.65	2.55	3.25	2.80	3.90	0.46	0.34	FL	52.4	80.2	42.2	57.4	47.2	67.4	7.80	5.72
	R	2.85	4.25	2.35	3.15	2.55	3.55	0.30	0.22	FR	35.8	60.2	26.4	39.4	31.4	49.2	4.69	3.44
10	S	3.30	4.80	2.75	3.35	3.00	4.05	0.45	0.33	FL	54.2	81.8	44.0	59.2	49.2	68.8	7.86	5.76
	R	2.90	4.30	2.40	3.25	2.60	3.65	0.30	0.22	FR	37.8	62.4	28.4	41.8	33.4	51.6	4.65	3.41
20	S	3.65	5.10	3.05	3.65	3.35	4.40	0.52	0.38	FL	58.4	86.2	48.4	66.2	52.8	73.4	8.24	6.04
	R	3.10	4.75	2.75	3.55	3.00	4.15	0.33	0.24	FR	39.2	66.2	34.2	45.8	37.2	54.8	4.71	3.45
30	S	4.30	5.95	3.65	4.40	4.05	5.25	0.61	0.45	FL	65.2	94.4	54.6	70.8	60.4	83.2	8.33	6.11
	R	3.35	4.80	2.85	3.75	3.10	4.25	0.31	0.23	FR	47.4	73.6	37.0	52.2	42.6	61.8	4.80	3.52
40	S	5.05	6.65	4.45	5.15	4.75	5.85	0.64	0.47	FL	79.6	97.2	66.8	83.4	74.2	94.8	8.50	6.23
	R	3.85	5.45	3.25	4.15	3.60	4.75	0.40	0.29	FR	53.2	80.4	44.2	58.6	49.2	71.2	4.95	3.63
50	S	5.75	7.20	5.25	5.95	5.45	6.45	0.53	0.39	FL	84.6	110.8	74.2	91.2	79.8	100.6	8.37	6.14
	R	4.05	5.60	3.60	4.35	3.80	4.80	0.30	0.22	FR	67.4	87.6	54.4	68.0	62.4	79.2	5.02	3.68
60	S	5.75	6.40	5.40	5.75	5.60	6.05	0.40	0.29	FL	86.2	103.4	77.0	87.6	82.2	96.2	8.31	6.09
	R	4.25	5.30	3.95	4.60	4.05	4.90	0.25	0.19	FR	73.6	91.4	61.2	72.4	69.4	84.0	4.90	3.59
70	S	4.05	4.20	3.95	4.05	3.95	4.10	0.30	0.22	FL	67.2	71.2	65.2	67.7	65.6	68.5	5.77	4.23
	R	3.45	3.60	3.40	3.50	3.45	3.55	0.22	0.16	FR	54.8	59.2	49.8	52.8	51.6	55.4	3.91	2.87
80	S	2.55	2.50	2.75	2.45	2.65	2.75	0.22	0.16	FL	36.6	36.1	35.2	34.5	37.2	35.3	3.34	2.45
	R	2.65	2.65	2.60	2.75	2.65	2.60	0.15	0.11	FR	23.6	23.2	22.4	24.2	24.2	23.8	2.54	1.86
90	S	1.90	1.95	1.90	1.85	1.80	1.85	0.08	0.06	FL	24.8	24.5	24.1	23.6	22.8	23.9	1.58	1.16
	R	1.95	1.90	2.00	1.95	1.85	1.95	0.07	0.05	FR	14.2	14.6	14.0	14.2	14.8	13.8	1.13	0.83
100	S	1.85	1.95	1.95	1.80	1.85	1.80	0.08	0.06	FL	23.2	24.5	24.9	23.2	24.2	24.6	1.54	1.13
	R	1.95	1.95	1.90	2.00	1.95	2.00	0.10	0.07	FR	14.0	14.4	14.6	14.6	14.0	14.2	1.19	0.87
L.S.D.																		
0.01	S	0.36	0.41	0.39	0.37	0.43	0.35			FL	4.92	4.58	5.47	5.26	4.63	5.16		
	R	0.25	0.31	0.31	0.29	0.32	0.36			FR	3.75	4.16	3.96	3.69	4.81	4.07		
0.05	S	0.27	0.31	0.29	0.28	0.32	0.26			FL	3.68	3.42	4.09	3.93	3.46	3.86		
	R	0.19	0.23	0.23	0.22	0.24	0.27			FR	2.80	3.11	2.96	2.76	2.85	3.04		

S = Shoot, R = Root

FL = Flower, FR = Fruit

Each value is mean of five replicates.

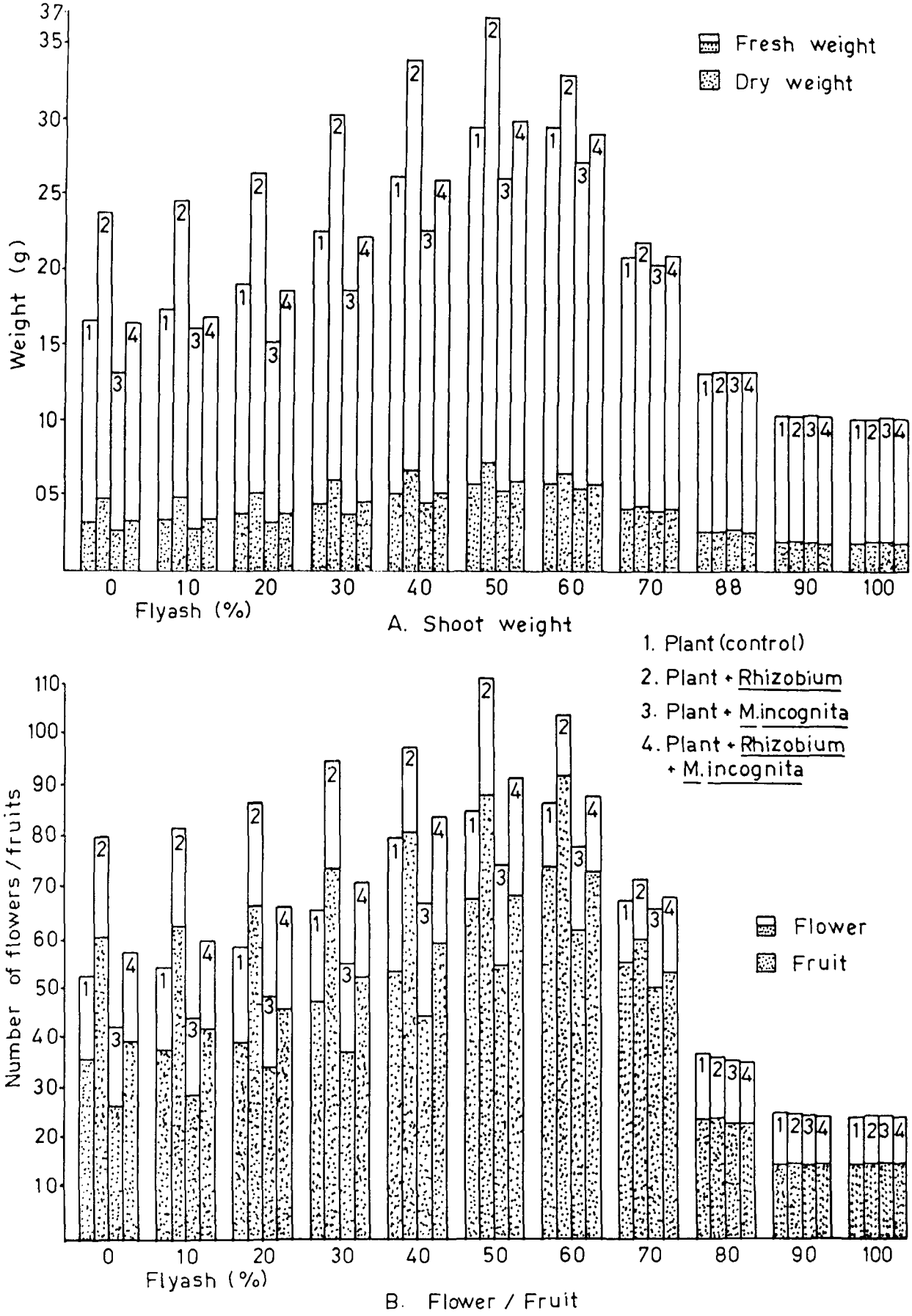

Fig.5. Interactive effects of flyash amended soil, M.incognita and root nodule bacteria on some parameters of lentil.

greater in the plants infected with M. incognita. Root galling and eggmass production of both M. incognita and M. javanica were suppressed in the presence of Rhizobium. Flyash level upto 50% apparently favoured the nematodes which resulted in stepwise increase in the galls upto 50% flyash level. Root galling gradually declined from 60% onward and no galling was observed in 90% and 100%. The eggmass production of both the nematodes was suppressed by the flyash. The number of eggmass gradually decreased with the increasing level of flyash from 10 to 60%. The eggmass production was completely inhibited at 70-100% flyash levels. The suppression of root galling and eggmass production by Rhizobium was adversely affected with the increasing level of flyash (Table 23).

Root nodulation was suppressed by flyash content of the amended soils. Number of root nodules gradually decreased upto 80% flyash level. At 90% and 100% flyash levels, the root nodulation was completely inhibited. The number of functional nodules also decreased gradually with the increasing level of flyash. The adverse effect of both M. incognita and M. javanica on root nodulation was gradually reduced upto 60% flyash level. No adverse effect of the nematodes on root nodulation was found in 70% and onward. The number of root nodules infected with root-knot nematodes gradually increased upto 50% flyash

Table 23. Interactive effects of flyash amended soil, root-knot nematodes and root nodules bacteria on root galling, eggmass production and bacterial nodulation on lentil.

Flyash (%)		Gall/Eggmass					L.S.D.			Nodule			L.S.D.	
		P	P+Rh	P+Mi	P+Rh+Mi	P+Mj	P+Rh+Mj	0.01	0.05	P	P+Rh+Mi	P+Rh+Mj	0.01	0.05
00 (Control)	G	-	-	136.4	107.2	64.4	52.8	12.24	8.73	T 226.4	154.6 (25.8)	196.0 (16.4)	23.77 (4.10)	16.34 (2.47)
	E	-	-	93.2	70.6	37.8	34.2	7.89	5.63	F 203.2	110.4	151.4	24.08	16.55
10	G	-	-	141.2	116.4	67.4	55.2	10.64	7.59	T 212.2	149.8 (27.0)	189.0 (16.4)	24.52 (4.30)	16.85 (2.59)
	E	-	-	75.4	62.6	33.0	31.2	5.89	4.20	F 192.6	106.2	147.2	22.87	15.72
20	G	-	-	145.6	128.4	70.2	62.6	13.21	9.42	T 190.6	138.4 (31.2)	172.4 (19.4)	19.48 (3.95)	13.39 (2.38)
	E	-	-	50.2	44.2	25.6	21.4	5.27	3.76	F 170.8	97.2	134.2	21.27	14.62
30	G	-	-	149.2	135.0	73.2	65.4	12.86	9.17	T 163.0	126.4 (35.6)	149.2 (23.0)	15.19 (5.09)	10.44 (3.07)
	E	-	-	36.6	34.8	21.6	19.8	3.07	2.19	F 142.2	84.6	117.0	16.50	11.34
40	G	-	-	155.6	141.2	78.4	70.2	9.42	6.32	T 121.4	105.2 (41.4)	119.8 (28.4)	16.62 (3.21)	11.41 (3.14)
	E	-	-	21.0	18.4	15.4	13.8	2.05	1.46	F 111.3	68.6	95.2	12.69	8.72
50	G	-	-	176.8	163.2	90.0	86.4	9.67	6.90	T 108.4	90.2 (49.2)	103.6 (34.2)	9.49 (5.12)	6.52 (3.09)
	E	-	-	15.4	13.0	11.2	10.4	1.72	1.23	F 94.0	60.4	84.2	10.69	7.35
60	G	-	-	93.6	89.6	69.2	61.0	8.47	6.04	T 91.6	79.8 (25.4)	89.4 (14.8)	7.99 (3.58)	5.49 (2.16)
	E	-	-	7.2	7.0	5.6	5.2	0.95	0.68	F 72.8	48.2	63.2	7.74	5.22
70	G	-	-	35.0	28.2	21.4	18.6	3.32	2.37	T 32.2	26.4 (11.0)	30.2 (7.4)	3.19 (2.04)	2.19 (1.23)
	E	-	-	0.0	0.0	0.0	0.0	0.00	0.00	F 17.4	18.4	23.2	2.87	1.97
80	G	-	-	13.2	13.8	11.7	11.4	1.99	1.42	T 8.4	8.6 (0.0)	8.4 (0.0)	0.74 (0.00)	0.51 (0.00)
	E	-	-	0.0	0.0	0.0	0.0	0.00	0.00	F 5.2	5.4	5.4	0.71	0.49
90	G	-	-	0.0	0.0	0.0	0.0	0.00	0.00	T 0.0	0.0 (0.0)	0.0 (0.0)	0.00 (0.00)	0.00 (0.00)
	E	-	-	0.0	0.0	0.0	0.0	0.00	0.00	F 0.0	0.0	0.0	0.00	0.00
100	G	-	-	0.0	0.0	0.0	0.0	0.00	0.00	T 0.0	0.0 (0.0)	0.0 (0.0)	0.00 (0.00)	0.00 (0.00)
	E	-	-	0.0	0.0	0.0	0.0	0.00	0.00	F 0.0	0.0	0.0	0.00	0.00
L.S.D.														
0.01	G	-	-	8.39	9.47	6.26	7.02			T 19.04	15.61 (3.24)	16.27 (2.74)		
	E	-	-	9.27	9.57	5.83	5.58			F 16.67	11.93	12.50		
0.05	G	-	-	6.27	7.08	4.68	5.25			T 14.23	11.67 (2.42)	12.16 (2.05)		
	E	-	-	6.98	7.15	4.36	4.17			F 12.46	8.92	9.34		

G = Gall, E = Eggmass

T = Total, F = Functional. (The number of nodules infected with root-knot nematode are given in parentheses)

Each value is mean of five replicates.

level. A declining trend in the number of nodules infected with root-knot nematodes was observed from 60% onward and in 80, 90 and 100% flyash levels, no infection of root nodules was observed (Table 23).

Leaf pigments and seed proteins

The leaf pigments and seed proteins of lentil were promoted by flyash contents in the soils. The pigment and protein contents gradually increased upto 60%. This gradual increase showed a declining trend from 70% onward. Chlorophyll contents increased significantly in 80% flyash concentration, while the protein content in 80% flyash concentration decreased significantly except the insoluble protein. The adverse effects of root-knot nematodes and favourable effects of root nodule bacteria on leaf pigments and seed proteins were reduced by the flyash of the soils. The adverse effects of the nematodes were affected by the presence of Rhizobium. These influences showed a direct relationship with flyash levels (Tables 24 and 25, Figs. 6A and 6B).

Leaf epidermal characters

The leaf epidermal characters of lentil were influenced differently by the artificial amendment of soil with flyash. The number of stomata and size of stomata and stomatal aperture gradually increased with the increasing level

Table 24. Interactive effect of flyash amended soil, root-knot nematodes and root-nodule bacteria on chlorophyll content of leaves of lentil.

Treatment		Chlorophyll (mg/g)											L.S.D.	
		00(Control)	10	20	30	40	50	60	70	80	90	100	0.01	0.05
P (Control)	A	0.724	0.792	0.879	0.951	1.139	1.270	1.299	1.101	0.768	0.591	0.576	0.041	0.031
	B	0.563	0.608	0.676	0.732	0.878	0.980	1.002	0.851	0.593	0.455	0.443	0.036	0.027
	T	1.362	1.491	1.659	1.791	2.147	2.389	2.443	2.069	1.445	1.112	1.083	0.055	0.041
P+Rh	A	0.902	0.980	1.079	1.158	1.370	1.484	1.453	1.154	0.768	0.582	0.575	0.036	0.027
	B	0.714	0.754	0.831	0.893	1.058	1.147	1.122	0.894	0.605	0.448	0.442	0.032	0.024
	T	1.716	1.844	2.036	2.181	2.583	2.792	2.734	2.172	1.473	1.095	1.081	0.058	0.043
P+Mi	A	0.594	0.664	0.746	0.814	0.983	1.125	1.182	1.067	0.776	0.586	0.582	0.040	0.030
	B	0.457	0.509	0.573	0.626	0.757	0.867	0.911	0.825	0.600	0.451	0.448	0.039	0.029
	T	1.129	1.251	1.409	1.534	1.854	2.106	2.224	2.007	1.462	1.103	1.094	0.062	0.048
P+Rh+Mi	A	0.648	0.730	0.816	0.882	1.059	1.192	1.229	1.105	0.759	0.597	0.572	0.037	0.028
	B	0.496	0.560	0.627	0.678	0.816	0.919	0.947	0.855	0.586	0.460	0.440	0.041	0.031
	T	1.252	1.374	1.541	1.661	1.997	2.242	2.312	2.079	1.429	1.123	1.075	0.070	0.052
P+Mj	A	0.664	0.727	0.811	0.880	1.063	1.214	1.243	1.063	0.765	0.594	0.579	0.042	0.032
	B	0.503	0.558	0.623	0.677	0.819	0.929	0.959	0.822	0.591	0.457	0.445	0.037	0.031
	T	1.244	1.370	1.531	1.657	2.004	2.265	2.340	1.998	1.440	1.117	1.089	0.066	0.049
P+Rh+Mj	A	0.788	0.849	0.943	1.014	1.221	1.359	1.355	1.110	0.761	0.592	0.573	0.041	0.031
	B	0.523	0.653	0.726	0.781	0.942	1.050	1.045	0.859	0.588	0.455	0.441	0.024	0.028
	T	1.481	1.598	1.780	1.910	2.302	2.557	2.548	2.087	1.432	1.113	1.077	0.060	0.045
L.S.D.														
0.01	A	0.079	0.072	0.085	0.080	0.079	0.080	0.083	0.078	0.052	0.034	0.033		
	B	0.059	0.060	0.064	0.065	0.069	0.065	0.086	0.069	0.042	0.033	0.035		
	T	0.139	0.140	0.126	0.136	0.132	0.143	0.154	0.134	0.097	0.071	0.067		
0.05	A	0.058	0.053	0.062	0.059	0.058	0.059	0.061	0.057	0.038	0.025	0.024		
	B	0.043	0.044	0.047	0.048	0.051	0.048	0.063	0.051	0.031	0.024	0.026		
	T	0.102	0.103	0.093	0.100	0.097	0.105	0.113	0.098	0.071	0.052	0.049		

A = Chl.a, B = Chl.b, T = Total chl.

Each value is mean of five replicates.

Table 25. Interactive effects of flyash amended soil, root-knot nematodes and root nodule bacteria on protein content of seeds of lentil.

Treatment		Protein (%)											L.S.D.	
		00(Control)	10	20	30	40	50	60	70	80	90	100	0.01	0.05
P (Control)	S	10.46	10.52	10.60	10.70	10.84	10.92	11.02	10.26	9.78	9.26	9.20	0.21	0.16
	I	13.94	14.36	15.02	15.40	15.88	16.04	16.18	14.98	14.30	13.60	13.54	0.24	0.18
	T	24.40	24.88	25.62	26.10	26.72	26.96	27.20	25.24	24.08	22.86	22.74	0.39	0.29
P+Rh	S	11.56	11.56	11.62	11.66	11.72	11.64	11.46	10.44	9.74	9.28	9.18	0.23	0.17
	I	15.28	15.30	15.54	15.80	16.22	16.24	16.28	15.30	14.28	13.60	13.52	0.28	0.21
	T	26.84	26.86	27.16	27.46	27.94	27.90	27.74	25.74	24.02	22.86	22.70	0.41	0.31
P+Mi	S	10.16	10.22	10.38	10.44	10.54	10.60	10.80	10.18	9.76	9.22	9.20	0.21	0.16
	I	13.52	13.94	14.54	15.02	15.66	15.96	16.12	14.86	14.30	13.58	13.54	0.23	0.17
	T	23.68	24.16	24.92	25.46	26.20	26.56	26.92	25.04	24.06	22.80	22.74	0.37	0.28
P+Rh+Mi	S	10.60	10.64	10.63	10.72	10.82	11.12	10.84	10.24	9.80	9.26	9.22	0.19	0.14
	I	13.92	14.36	15.04	15.50	16.10	16.08	16.38	14.94	14.32	13.62	13.56	0.21	0.16
	T	24.52	25.00	25.72	26.22	26.92	27.20	27.22	25.18	24.12	22.88	22.78	0.33	0.25
P+Mj	S	10.26	10.34	10.46	10.50	10.68	10.84	10.90	10.22	9.74	9.24	9.22	0.27	0.15
	I	13.66	14.08	14.72	15.24	15.78	15.98	16.24	14.98	14.28	13.60	13.54	0.21	0.16
	T	23.92	24.42	25.18	25.74	26.46	26.82	27.14	25.20	24.02	22.84	22.76	0.32	0.24
P+Rh+Mj	S	10.88	10.94	11.02	11.18	11.30	11.46	11.22	10.40	9.76	9.24	9.22	0.27	0.20
	I	14.24	14.70	15.42	15.72	16.18	16.16	16.32	15.18	14.28	13.60	13.56	0.24	0.18
	T	25.12	25.64	26.44	26.90	27.48	27.62	27.54	25.58	24.04	22.84	22.78	0.36	0.27
L.S.D.														
0.01	S	0.40	0.35	0.41	0.42	0.46	0.40	0.25	0.22	0.15	0.11	0.12		
	I	0.34	0.39	0.40	0.38	0.42	0.41	0.29	0.23	0.18	0.15	0.14		
	T	0.85	0.75	0.80	0.85	0.86	0.76	0.59	0.59	0.29	0.23	0.22		
0.05	S	0.29	0.26	0.30	0.31	0.34	0.29	0.18	0.16	0.11	0.08	0.09		
	I	0.25	0.27	0.29	0.28	0.31	0.30	0.21	0.17	0.13	0.11	0.10		
	T	0.62	0.55	0.59	0.62	0.63	0.56	0.43	0.43	0.21	0.17	0.16		

S = Soluble, I = Insoluble, T = Total

Each value is mean of five replicates.

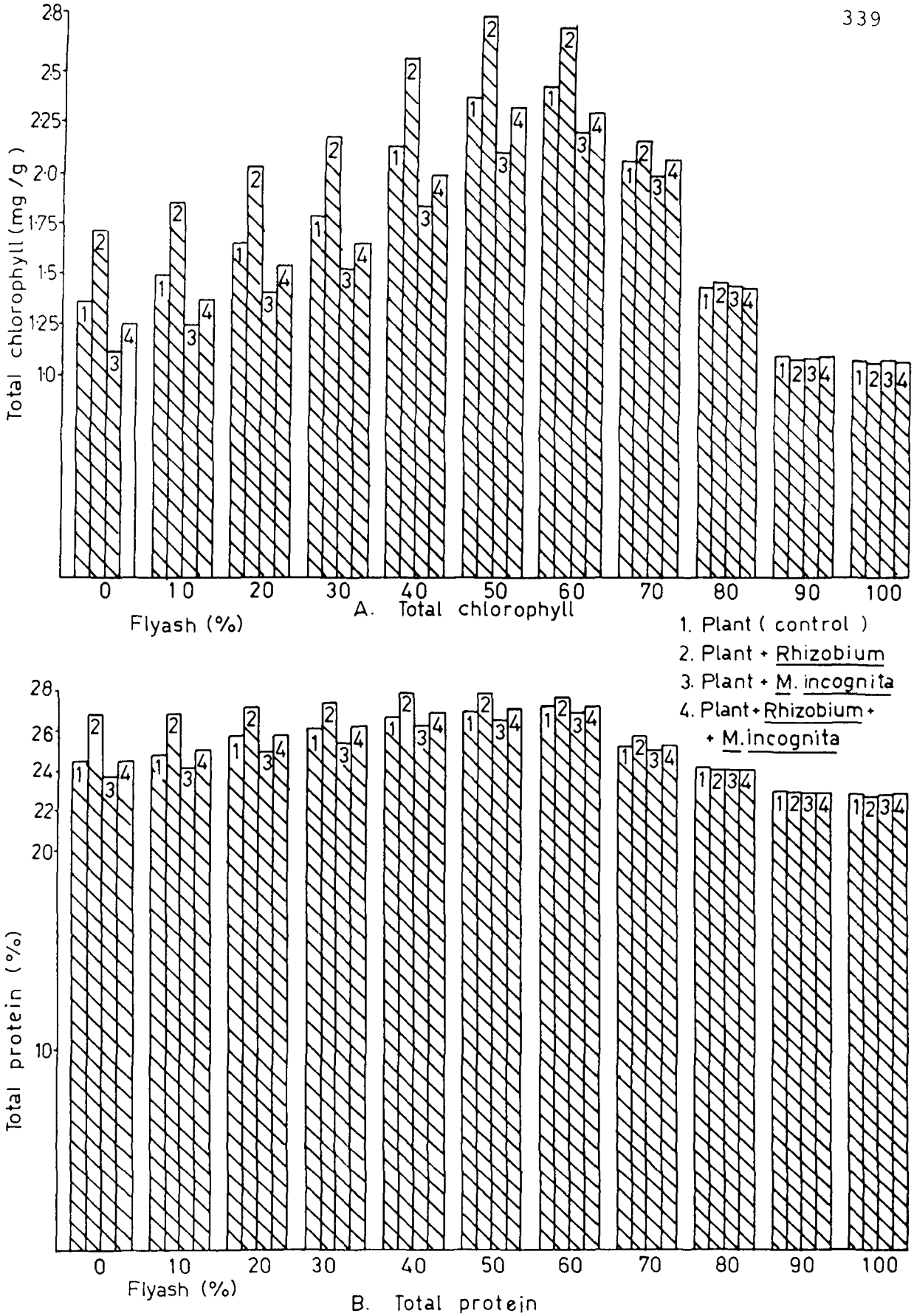

Fig.6. Interactive effects of flyash amended soil, M. incognita and root nodule bacteria on some parameters of lentil.

Table 26. Interactive effects of flyash amended soil, root-knot nematodes and root nodule bacteria on number of stomata on leaves of lentil.

Flyash (%)		Number of stomata/cm^2						L.S.D.	
		P	P+Rh	P+Mi	P+Rh+Mi	P+Mj	P+Rh+Mj	0.01	0.05
00 (Control)	L	4936.83	5430.51	4485.03	4754.13	4613.86	5028.17	228.43	167.59
	U	3538.06	3863.18	3173.15	3458.73	3251.89	3577.08	176.70	129.56
10	L	4961.51	5456.67	4551.85	4806.75	4658.70	5031.39	209.52	153.62
	U	3591.13	3986.16	3241.09	3500.38	3328.20	3654.37	181.65	133.19
20	L	5035.57	5463.59	4671.21	4881.42	4754.51	5078.40	211.79	155.29
	U	3697.27	4055.91	3385.78	3622.79	3481.42	3759.94	184.69	135.42
30	L	5233.04	5625.52	4886.12	5091.34	4974.37	5277.81	231.13	169.47
	U	3821.10	4172.65	3521.76	3740.10	3621.90	3889.92	179.82	131.85
40	L	5479.88	5836.07	5159.96	5366.36	5304.82	5580.67	226.82	166.42
	U	3998.01	4341.83	3557.83	3735.72	3667.09	3916.45	182.82	134.05
50	L	5578.62	5829.66	5364.06	5524.98	5442.55	5633.04	188.78	138.42
	U	4068.77	4312.90	3875.02	4030.02	3988.99	4188.44	191.72	140.57
60	L	5627.99	5796.83	5517.63	5627.99	5544.81	5683.43	161.26	118.24
	U	4104.15	4247.79	3984.61	4064.31	4043.50	4164.80	187.19	137.25
70	L	5282.41	5388.05	5219.77	5298.07	5230.11	5324.25	163.13	119.61
	U	3821.10	3916.63	3746.18	3802.37	3764.63	3832.39	165.91	121.68
80	L	4657.39	4631.45	4724.67	4619.82	4532.94	4685.35	138.32	101.42
	U	3245.93	3259.44	3308.19	3278.56	3289.71	3218.42	151.92	111.39
90	L	4488.03	4539.65	4462.29	4494.41	4542.76	4478.16	118.55	86.92
	U	3158.98	3126.45	3182.72	3226.39	3146.24	3197.83	149.27	109.45
100	L	4459.85	4432.81	4509.67	4489.19	4465.56	4492.34	120.56	88.40
	U	3179.39	3143.55	3182.04	3230.78	3132.41	3154.37	151.82	111.32
L.S.D.									
0.01	L	112.56	102.21	129.05	90.73	96.97	87.39		
	U	106.06	91.22	130.37	152.00	140.24	120.03		
0.05	L	84.13	76.39	96.45	67.81	72.48	65.32		
	U	79.27	68.18	97.44	113.61	104.82	91.21		

L = Lower surface, U = Upper surface

Each value is mean of five replicates.

Table 27. Interactive effects of flyash root-knot nematodes and root-nodule bacteria on the size of stomata & stomatal aperture on leaves of lentil.

Flyash %		Size of stomata (μm^2) P	P+Rh	P+Mi	P+Rh+Mi	P+Mj	P+Rh+Mj	L.S.D. 0.01	L.S.D. 0.05	Size of Stomatal aperture (μm^2) P	P+Rh	P+Mi	P+Rh+Mi	P+Mj	P+Rh+Mj	L.S.D. 0.01	L.S.D. 0.05
00 (Control)	L	660.44	713.28	582.91	609.14	594.98	636.64	46.44	34.07	86.44	92.47	77.18	80.26	78.56	82.49	7.45	5.46
	U	591.12	656.14	517.62	548.67	527.79	575.29	54.10	39.67	69.15	75.37	60.66	63.39	61.47	66.14	4.73	3.47
10	L	686.86	736.31	610.54	635.57	624.42	665.63	43.19	31.27	88.17	93.99	79.22	82.02	80.67	84.38	7.68	5.63
	U	599.99	659.99	530.02	557.18	540.53	582.69	54.60	40.03	71.22	76.99	63.14	63.67	64.05	67.96	4.94	3.62
20	L	676.29	718.90	609.27	629.38	623.31	660.71	47.50	34.83	91.19	96.67	82.53	81.17	84.05	87.50	7.38	5.41
	U	621.86	674.72	596.79	621.86	565.33	602.07	53.93	39.54	73.99	79.02	66.66	68.79	67.26	70.63	4.92	3.61
30	L	693.46	724.67	636.20	654.02	645.08	677.33	48.58	35.62	92.06	86.66	84.46	86.65	86.44	89.21	7.27	5.33
	U	641.37	686.26	583.06	604.05	590.58	623.23	57.50	42.16	74.68	77.84	67.39	69.48	68.19	71.06	4.83	3.54
40	L	729.79	551.68	680.14	693.74	687.18	709.17	49.43	34.24	92.75	95.72	87.34	88.82	89.10	90.97	7.58	5.56
	U	666.78	695.46	622.00	639.42	624.33	651.18	63.66	46.68	75.37	78.16	70.11	72.08	70.97	73.24	4.20	3.15
50	L	739.69	754.49	707.84	714.92	714.68	725.40	43.03	31.55	94.22	96.10	90.60	91.95	91.92	93.76	7.49	5.49
	U	673.88	690.72	641.79	651.41	647.96	660.92	59.01	43.27	76.76	77.26	71.78	72.86	72.47	74.07	4.06	2.98
60	L	746.30	753.76	731.66	735.32	738.91	746.30	40.64	29.80	95.08	96.03	93.22	93.69	94.14	95.08	7.15	5.24
	U	679.79	689.98	663.21	669.84	663.21	673.16	56.18	41.19	77.45	78.61	75.56	76.31	75.93	77.07	3.31	2.43
70	L	680.25	687.05	671.52	698.38	674.85	622.09	30.85	22.62	89.90	97.09	87.68	91.20	89.25	94.61	5.85	4.29
	U	814.74	622.14	696.87	611.73	609.88	615.98	49.43	36.24	72.61	73.34	72.19	77.24	72.58	78.39	3.18	2.33
80	L	626.99	637.42	656.21	611.52	643.59	650.76	26.40	19.36	81.16	83.45	83.22	79.92	80.46	82.69	4.99	3.66
	U	552.45	561.39	557.42	578.18	539.56	570.67	36.66	26.88	62.86	63.04	62.53	61.49	62.38	60.96	2.40	1.76
90	L	589.66	553.24	592.56	612.71	560.83	573.14	19.33	14.17	78.58	76.91	79.48	80.06	76.89	78.67	4.32	3.17
	U	518.53	517.22	529.72	535.81	521.45	509.36	27.70	20.31	58.39	57.16	59.99	58.06	57.18	59.24	2.11	1.55
100	L	564.60	591.08	562.89	545.32	573.41	551.92	20.49	15.02	79.64	76.33	80.49	77.68	79.37	78.24	4.41	2.23
	U	531.62	525.04	522.59	529.38	519.45	531.08	25.41	18.63	59.67	59.32	57.16	57.62	58.39	60.05	2.17	1.59
L.S.D.																	
0.01	L	28.85	24.40	32.90	30.40	25.46	25.34			4.51	3.93	4.56	5.38	4.79	5.20		
	U	36.78	25.92	39.12	33.52	30.55	35.54			3.81	4.24	4.66	5.31	5.53	4.33		
0.05	L	21.56	18.24	24.59	22.72	19.03	18.94			3.37	2.94	3.41	4.02	3.58	3.89		
	U	27.49	19.37	29.24	25.04	22.83	26.56			2.85	3.17	3.48	3.97	4.13	3.24		

L = Lower surface, U = Upper surface

Each value is mean of five replicates.

Table 28. Interactive effects of flyash amended soil, root-knot nematodes and root nodule bacteria on the number and length of trichomes on leaves of lentil.

Flyash (%)		Number of trichomes /cm^2						L.S.D.		Length of trichomes (μm)						L.S.D.	
		P	P+Rh	P+Mi	P+Rh+Mi	P+Mj	P+Rh+Mj	0.01	0.05	P	P+Rh	P+Mi	P+Rh+Mi	P+Mj	P+Rh+Mj	0.01	0.05
00 (Control)	L	2591.84	1963.52	2901.94	2545.63	2825.11	2242.15	172.99	126.84	733.17	591.26	784.49	694.23	762.50	630.17	56.04	41.09
	U	1548.53	1082.87	1773.05	1453.42	1718.87	1282.74	169.49	124.27	680.16	507.58	741.37	633.65	718.25	552.56	40.11	29.41
10	L	2516.35	1928.24	2798.18	2476.27	2722.69	2186.90	162.74	119.32	718.79	583.44	763.36	680.36	740.36	616.96	59.30	43.48
	U	1474.79	1061.00	1669.46	1391.22	1622.27	1247.90	161.51	118.42	660.35	500.26	713.18	616.40	693.37	541.69	39.10	28.67
20	L	2399.85	1889.35	2639.84	2367.57	2567.84	2113.45	168.12	123.27	691.67	566.94	726.25	657.24	715.88	604.12	52.73	38.66
	U	1382.62	1047.44	1534.70	1323.02	1493.23	1199.38	162.34	119.03	638.65	500.90	680.16	601.91	661.00	535.22	39.99	29.32
30	L	2293.66	1834.93	2500.09	2272.81	2419.82	2024.25	149.12	109.34	688.86	570.47	709.41	650.83	701.26	604.54	48.72	35.72
	U	1346.55	1031.84	1481.20	1200.30	1440.81	1176.17	154.63	113.38	629.78	512.01	666.30	599.20	654.97	540.40	35.34	25.91
40	L	2196.47	1815.23	2350.23	2196.45	2266.76	1945.72	132.91	97.45	666.52	579.58	693.18	644.82	686.51	610.23	49.36	36.19
	U	1301.29	1016.63	1405.39	1260.49	1379.36	1144.70	132.12	96.87	612.76	516.66	643.39	588.65	640.33	543.57	33.93	24.88
50	L	2142.02	1878.96	2249.12	2063.41	2184.86	1933.50	140.35	102.91	648.82	589.84	661.80	618.50	658.56	604.18	44.53	32.65
	U	1269.29	1067.74	1345.44	1180.21	1320.06	1128.26	133.99	98.24	596.63	532.71	617.51	571.77	611.55	555.95	30.13	22.09
60	L	2159.87	1981.53	2224.66	2079.12	2181.47	2001.34	124.62	91.37	654.62	623.44	661.16	630.80	657.89	626.56	40.47	29.67
	U	1279.78	1142.66	1318.17	1231.93	1305.37	1186.70	111.00	81.39	607.29	572.91	619.43	601.39	616.40	587.04	26.64	19.53
70	L	2057.02	2139.30	2016.69	2065.09	2036.65	2097.75	103.22	75.68	704.97	722.59	700.76	713.38	702.86	716.92	33.59	24.63
	U	1460.88	1533.82	1439.29	1489.67	1446.42	1508.61	89.55	65.66	647.77	670.45	640.09	656.73	641.36	607.36	26.92	19.74
80	L	3671.77	3629.49	3742.86	3655.04	3629.19	3684.62	90.26	66.18	784.49	766.21	760.39	751.87	797.61	749.27	26.91	19.73
	U	1703.38	1768.45	1679.16	1652.39	1771.32	1727.63	73.39	53.81	741.37	736.92	755.31	729.45	742.82	724.59	22.26	16.32
90	L	2462.25	2509.32	2416.09	2512.82	2483.18	2497.45	99.92	73.26	806.49	824.16	839.58	789.62	793.47	814.03	25.29	18.54
	U	1756.29	1753.41	1740.75	1821.20	1774.73	1788.28	75.39	55.28	768.58	762.61	773.45	759.76	761.09	781.11	19.22	14.09
100	L	2486.43	2460.91	2521.45	2463.44	2456.31	2469.18	97.37	71.39	792.56	781.25	807.18	789.38	801.57	783.48	24.94	18.29
	U	1768.36	1784.09	1761.42	1799.65	1759.72	1771.55	73.35	53.78	770.69	784.29	763.41	771.11	769.34	759.98	19.41	14.23
L.S.D.																	
0.01	L	105.04	87.14	151.84	131.95	165.34	114.21			52.10	57.20	41.88	37.22	45.73	34.05		
	U	138.52	96.55	155.71	131.31	161.05	105.10			33.27	20.26	30.30	24.70	33.96	22.66		
0.05	L	78.51	65.13	113.49	98.62	123.58	85.36			38.91	42.75	31.30	27.82	34.18	25.45		
	U	103.53	72.16	116.38	98.14	120.37	78.55			24.87	15.14	22.65	18.46	25.38	16.94		

L = Lower surface, U = Upper surface

Each value is mean of five replicates.

of flyash upto 60%. The increase in these parameters started declining from 70% onwards.

The effects of root-knot nematodes and root nodule bacteria alone or in combination on leaf epidermal characters were gradually suppressed upto 70% flyash level, and their effects were completely suppressed at 80% and onwards (Tables 26, 27). The number and length of trichomes gradually decreased with the increasing level of flyash upto 50%. This decrease was reduced at 60% and 70% flyash levels. The number and length of trichomes increased significantly at 80% flyash level and this increasing trend was persistent upto 100%. The individual and combined effects of the root-knot nematodes and root nodule bacteria, were suppressed gradually upto 70% flyash level and was completely eliminated at 80% and onwards (Table 28).

DISCUSSION

Ambient flyash polluted soil was beneficial for the plant growth and yield of chick-pea and lentil. Since the deposition of flyash was more in the soil of 1/2 km (S_1) than 2 km (S_2) from the stack of the thermal power plant, the improvements in growth and yield of the plants were greater in S_1 soil than S_2 soil. Associated with better plant growth, leaf pigments and seed proteins of both crops were also increased. In the artificial amendment of soil,

the leaf pigments and seed proteins increased gradually with the increasing plant growth but declined at higher concentrations where plant growth was also poor.

Epidermal structures of leaves of the crops considered, responded favourably as structural demand for better water absorption, greater translocation and transpiration in plants showing improved growth. The response pattern of various leaf epidermal structures to the flyash pollution of the soil differed. Stomata and trichome-hydathodes responded favourably and number, size and aperture of stomata and length of trichome-hydathodes increased but the trichomes responded negatively and their number and length declined. These influences were correlated with the concentration of flyash.

As a structural adaptation for increased water absorption because of greater water holding capacity and improved plant growth in flyash polluted soil, number and size of stomata and stomatal aperture size increased in the leaves which in turn facilitated the greater absorption of water. Trichome-hydathodes, the secretory foliar appendages, secrete an aqueous solution containing some inorganic and organic substances (Fahn, 1982; Shneff,1965; Perrin, 1970) are one of the characteristic features of chick-pea. They were also affected positively by the flyash polluted soil. In the new leaves the number and length of trichome-hydatho-

des increased possibly to meet the increased water pressure in leaves due to greater water absorption.

Trichomes, the leaf appandges, protect the leaf epidermal tissues and make an insulated layer on the leaf surface, through which they regulate the transpiration and also maintain the temperature of plants. When the plant growth was improved, the function of trichomes became of less importance and as a response their number and size declined. As a response of pollution stress caused by flyash, when the plants showed poor growth due to its toxic effects at higher concentrations, trichomes increased in number and length and number and length of trichome-hydathodes and number, size and aperture of stomata decreased to check transpiration.

The beneficial effect of flyash polluted soil on plant growth and yield was greater in chick-pea than lentil. This variation might be due to relative difference in their response to presence of flyash in soil.This increased growth and yield of chick-pea and lentil may be attributed to the presence of utilizable plant nutrients in flyash (Druzia et al., 1982). The artificial amendment of the soil with flyash upto 50%. also improved the plant growth and yield, which supports that some utilizable nutrients were available in flyash. In addition to nutrients, alterations in soil, in relation to some other factors like pH, cation

exchange capacity, water holding capacity and soil porosity also affected the growth of roots which reflected in shoot growth and yield. Flyash neutralizes soil pH and increases cation exchange capacity, water holding capacity and soil porosity (Jones and Straughan, 1978; Adriano, 1980; Elseewi et al., 1981). These favourable effects of flyash in soil might be also additionally responsible for amelioration of plant growth and yield of chick-pea and lentil.

In artificial amendments, beneficial effects of flyash beyond 50% for chick-pea and beyond 60% for lentil were diminished greatly and 80% onwards the amendments became harmful for plant growth and yield of both the crops. The beneficial effect of flyash was, therefore, optimal at 50-60%. The adverse effect of flyash at higher concentrations may be due to toxic effects of the compounds like dibenzofuran and dibenzo-p-dioxime mixture and heavy metals found in flyash (Helder et al. 1982; Mishra and Shukla, 1986; Wong and Wong, 1986; Kamath, 1978). At these levels of flyash the toxic substances might have been enough in concentration to suppress the plant growth. Additionally, the nutrients available in the soil which was used for amendments became low in concentration because of the increased concentration of flyash. This too might have contributed towards the poor growth and yield of the crops. Thus, the results showed that flyash emanating from the thermal

power plants are beneficial for plant growth of crops like chick-pea and lentil if present in appropriate concentrations at which the toxic substances claimed to be present in flyash are not harmful, because the beneficial effects mask the harmful effects and as a result better crop growth and yield are achieved. Even in ambient conditions this effect was evident because in the S_1 soil where deposition was greater, better plant growth occurred than in S_2 soil. Apparently the level of flyash in the soil at the both the sites was below the toxic threshold level for chick-pea and lentil.

At higher concentrations, the greater amount of toxic substances dominated over the favourable nutrients and ultimately the plant suffered. Additionally the proportion of soil gradually became smaller and in 90% and 100% flyash concentration very little or no field soil was available to support the normal plant growth.

Flyash in soil induced poor seed germination and less number of seedlings survived after emergence in both ambient polluted soils and in artificially amended soils. The adverse effect increased with increasing concentration of flyash either in ambient soil or in artificial amendments. The toxic substances apparently present in the flyash, even at low levels, inhibited seed germination and induced seedling mortality. Chick-pea and lentil seed at germination

and their seedlings immediately after germination at the tender age, were therefore, less tolerant to the toxic substances present in flyash. The seedlings which survived later showed better growth at the same levels of flyash. This indicates the variations in tolerance capacities of the crops at different stages of their growth.

Flyash pollution of soil, both in ambient and artificially amended soils suppressed root nodulation by Rhizobium. All the levels of flyash particulary in the artificial amendments were suppressive and suppression was directly correlated with the concentration of flyash. Complete suppression occurred at 90% and onward. The suppression of root nodulation reflected in the reduced dry weight of the plants. The toxic substances particularly heavy metals present in the flyash might be the cause of inhibition of root nodulation. Several heavy metals in the artificial conditions have been shown to be toxic for root nodulation (Khan et al., 1987, 1988). The death of nodules too in the flyash polluted soils.

Flyash, in both ambient and artificially polluted soils, suppressed the juvenile hatching of both M. incognita and M. javanica. The suppression of the juvenile hatching was greater in S_1 soil than in S_2 soil. In the soils artificially amended with flyash, the suppression in juvenile

hatching of M. incognita and M. javanica gradually increased with the increasing level of flyash upto 80 and 90% respectively. Further increase in flyash level completely inhibited juvenile hatching of the nematodes. Evidentaly, the toxic substances present in flyash inhibited juvenile hatching of nematodes.

Increased soil porosity,which favours movement of juveniles in the soil (O'Bannon and Reynolds, 1961; Sasser, 1954), might have helped the greater root ingress. Additionally, increased water holding capacity of the flyash amended soils might have also aided their greater penetration (Van Gundy, 1985). The greater ingress of juvenile caused more root-galling but eggmass production was suppressed, possibly because of the toxic effect of the flyash on the nematodes.

Root-knot nematodes and Rhizobium, were inhibitory to each other and interacted antagonistically and in their concomitant presence, the beneficial effects of Rhizobium were reduced. Flyash and Rhizobium individually were beneficial for plant growth and yield characters, leaf pigments and seed proteins,due to which the leaf epidermal characters were also affected. When Rhizobium and flyash were simultaneously applied, they interacted antagonistically. The toxic substances present in the flyash suppressed the root nodulation. Therefore, the interactive effects were deleterious for various plant growth and yield paramters, leaf

pigment and seed protein contents. Flyash also interacted antagonistically with root-knot nematodes. Flyash was more antagonistic to M. incognita than M. javanica. In antagonistic interactions with both root-knot nematodes and Rhizobium, flyash also adversely affected the interactive effects of root-knot nematodes and Rhizobium. The inhibitory effects of flyash in the antagonistic interaction either with Rhizobium or root-knot nematodes or both were concentration dependent, which increased with the increasing concentration in the artificially amended soil. In ambient condition also, the inhibitory effect of soil from 1/2 km (S_1) was greater than 2 km (S_2) because of the greater deposition of flyash in S_1 soil. In the artificial amendment of soils with flyash, plant growth of both the crops was adversely affected at higher concentrations i.e. from 70% and onward for lentil and 60% and onward for chick-pea. Accordingly all growth parameters and leaf pigment and seed protein contents declined. Leaf epidermal characters responded differently. Stomatal number, size and aperture and number of trichome-hydathodes (in chick-pea) decreased but the number of trichomes increased. Root-nodulation and root galling and eggmass production were completely suppressed.

SUMMARY

Flyash emanated from the Thermal Power Plant, Kasimpur improved the various physico-chemical properties of the soil which were found favourable to the plant growth. The improvement in the soil of S_1 was greater than S_2 soil.

Flyash polluted soils from both the sites were sandy loam while the unpolluted soil was loamy sand. Flyash pollution increased porosity, water holding capacity, conductivity and cation exchange capacity of the soils. Organic matter, sulphate and bicarbonate contents of the soils also increased. The increase was greater in S_1 soil than S_2 soil. Carbonate content was also greater in flyash polluted soil than unpolluted soil. Carbonate content of S_1 and S_2 soil, however, did not differ. Flyash pollution lowered soil pH. The pH of S_1 soil was less than S_2 soil.

Seed germination of chick-pea and lentil was inhibited and post-emergence mortality of their seedlings increased in the ambient flyash polluted soil as well as in the artificially flyash polluted soil. These effects of S_1 soil were greater than S_2 soil. Inhibitory effect on seed germination was greater for chick-pea but the post-emergence mortality of seedlings was greater for lentil. These adverse effects of flyash in the artificially amended soil showed stepwise increase upto 80% level. Thenafter, there was

no increase.

Juvenile hatching of the root-knot nematodes was suppressed by flyash in both the ambient and artificially polluted soils. The suppression was greater for M. incognita than M. javanica. The effect of S_1 soil was greater than S_2 soil in this respect also. A stepwise decrease occurred in juvenile hatching of M. incognita and M. javanica with the increasing level of flyash in the amended soil and was totally inhibited at 80 and 90% flyash levels, respec tively.

Flyash content of the soil, in general, was beneficial for plant growth and yield of both the crops. S_1 soil was more beneficial than S_2 soil. In the artificially amended soil, plant growth and yield showed stepwise increase upto 50% in chick-pea and 60% in lentil. Thenafter, a gradual decline was noticed upto 90% flyash level of the soil. The growth and yield were equal in 90 and 100%. The favourable effects of Rhizobium and adverse effects of root-knot nematodes on various considered parameters of plant growth and yield etc. were influenced. In artificially amended soil, the favourable effects of Rhizobium and adverse effects of the root-knot nematodes on plant growth and yield etc.were gradually reduced by the increasing level of flyash in the soil and the effects were completely elimina-ted at 80% level. Root galling and eggmass production were

variously affected by the flyash content of the soil. In the ambient flyash polluted soil, root galling was greater in S_1 soil than S_2 soil while the eggmass production was less in S_1 soil than S_2 soil. Root galling was promoted by the flyash and it increased upto 50%. Thenafter, an abrupt decline in the gall formation was recorded. Root galling of the nematodes was completely inhibited in 90% and 100% flyash level of soil. Eggmass production of the root-knot nematodes, however, showed stepwise decrease with the increasing level of flyash of the soil and the eggmass production of both the species was completely suppressed at 70%. Similar stepwise decrease occurred in the formation of root nodules by Rhizobium and was completely suppressed at 70 and 80% flyash levels in chick-pea and lentil respectively. The infection of root-nodules by root-knot nematodes was favoured by the flyash at lower levels (upto 50%).

Leaf pigments and seed proteins were increased by the flyash content of the soil. The increase was greater in S_1 than S_2 soil. In artificially amended soil, the leaf pigments and seed proteins increased upto 50% in chick-pea and upto 60% in lentil. Thenafter, a declining and trend was recorded upto 90%. The effects of Rhizobium and either species of Meloidogyne alone and in combination on leaf pigments and seed proteins were gradually suppressed

with the increasing level of flyash and completely eliminated at 80%.

Leaf epidermal characters responded variously to flyash pollution of the soil. The number of stomata, size of stomata and stomatal aperture and number and length of trichome-hydathodes (only in chick-pea) increased, while the number and length of trichomes decreased with increasing level of flyash upto 50% in chick-pea and 60% in lentil. Similar response of epidermal characters were observed in ambient flyash polluted soil. The effects of S_1 soil were greater than S_2 soil. Rhizobium and either species of Meloidogyne alone and in combination variously affected these parameters and suppression of these effects occurred with increasing level of flyash and their effects were completely eliminated at 80% and onwards.

LITERATURE CITED

Adriano, D.C. 1980. Utilization and disposal of flyash and other coal residues in terrestrial ecosystem. J. Environ. Qual. 9: 33-334.

Agrios, G.N. 1978. Plant Pathology, II Edition. Academic Press, New York. 703 pp.

Ahmad, A. And A.M. Khan 1964. Factors influencing larval hatching in the root-knot nematodes, Meloidogyne incognita (Kofoid and White, 1919), Chitwood, 1949 and M. javanica (Treub, 1885), Chitwood, 1949. I. Effect of temperature and hydrogen-ion concentration. Ind. Phytopath. 17: 98-101.

Alexander, M. 1984. Ecology of Rhizobium. In: Biological nitrogen fixation - Ecology, technology and physiology (Ed. M. Alexander) pp. 39-50. Plenum Press, New York and London.

Amundson, R.G. 1983. Yield reduction of soybean due to sulphur dioxide and nitrogen dioxide in combination. J. Environ. Qual. 12: 454-459.

Anonymous, 1986. Air Quality Monitoring-A course manual, National Environmental Engineering Research Insitute, Nagpur, India.

Ash, C.G. and O.N. Allen 1948. A comparison of methods recommended for the surface sterilization of leguminous seed. Soil Sci. Soc. Am. Proc. 13: 279-283.

Ashenden, T.W. and S.A. Bell 1987. The effects of simulated acid rain on the growth of three herbaceous species grown on a range of British soils. Environ. Pollut. 48: 295-310.

Ayala, A. 1962. Parasitism of bacterial nodules by the reniform nematode. J. Agric. Univ. Puerto Rico 46: 67-69.

Babich, H. and G. Stotzky 1982. Gaseous and heavy metal air pollutants. In: Experimental microbiology (Eds. R.G. Burns and J. Howard) pp. 631-670.Slater Blackwell Scientific publication, London.

Balasubramanian M. 1971. Root-knot nematodes and bacterial nodulation of soybean. Curr. Sci. 40: 69-71.

Barker, K.R. and D. Huisingh 1970. Histological investigations of the antagonistic interaction between Heterodera glycines and Rhizobium japonicum on soybean. Phytopathology 60: 1282-1283.

Barker, K.R. and R.S. Hussey 1976. Histopathology of nodular tissues of legumes infected with certain nematodes. Phytopathology 66: 850-885.

Barker, K.R., D. Huisheng and S.A. Johnston 1972. Antagonistic interaction between Heterodera glycines and Rhizobium japonicum on soybean. Phytopathology 62: 1201-1205.

Barker, K.R., P.S. Lehman and D. Huisingh 1971. Influence of nitrogen and Rhizobium japonicum on the activity of Heterodera glycines. Nematologica 17: 377-385.

Barrett, T.W. and H.M. Benedict 1970. Sulfur dioxide. In: Recognition of air pollution injury to vegetation: A pictorial atlas (Eds. J.S. Jacobson and A.C. Hill) PP. C1-C17. Air Pollution Control Association. Pittsburg, PA.

Bassus, W. 1968. The effects of industrial amission on the population of nematodes in the soil of pine forests. Pedobiologia 8: 289-295.

Beasley, E.W. 1942. Effects of some chemically inert dusts upon the transpiration rate of yellow colour plants. Plant Physiol. 17: 101-108.

Benedict, H.M. and W.H. Breen 1955. The use of weeds as a means of evaluating vegetation damage caused by air pollution. Proc. 3rd Natl. Air Pollut. Symp., Pasadena, California. pp. 179-180.

Bennett, J.P. and R.J. Oshima 1976. Carrot injury and yield response to ozone. J. Am. Soc. Hort. Sci. 101: 638-639.

Bennett, J.P., R.J. Oshima and L.F. Lippert 1979. Effect of ozone on injury and dry matter partitioning in pepper plant. Environ. Expt. Bot. 19: 33-39.

Bergeson, G.B. 1966. Mobilization of minerals in the infection site of root-knot nematodes. Phytopathology 56: 1287-1289.

Bergersen, F.J. and M.J. Briggs 1958. Studies on the bacterial component of soybean root nodules: Cytology and organization in the host tissue. J. Gen.Microbiol. 19: 482-490.

Bhatia, R.R. 1978. Effect of flyash on plant growth. M.Phil. Thesis, Jawahar Lal Nehru University, New Delhi, India.

Biscoe, P., M. Unsworth and H. Pinckney 1973. The effect of low concentration SO_2 on stomatal behaviour in Vicia faba. New Phytol. 72: 1299-1306.

Bisessar, S. and K.T. Palmer 1984. Ozone antioxidant spray and Meloidogyne hapla effects on tobacco (Nicotiana tabacum) cultivar Virginia-115. Atmos. Environ. 18: 1025-1028.

Bisessar, S. R.J. Rinne 1983. Effect of heavy metals and Meloidogyne hapla on celery grown on organic soil near a nickle refinery. Plant Dis. 67: 11-14.

Bissessar, S. and P.V. Temple 1977. Reduced ozone injury on virus infected tobacco in the field. Plant Dis. Rep. 61: 961-963.

Black, V.J. and M.H. Unsworth 1979. Effects of low concentrations of sulphur dioxide on net photosynthesis and dark respiration of Vicia faba. J. Exp. Bot. 30: 473-483.

Black, V.J. and M.H. Unsworth 1980. Stomatal response to sulphur dioxide and vapour pressure deficit. J. Exp. Bot. 31: 667-677.

Blum, U. and W.W. Heck 1980. Effects of acute exposures on snap bean at various stages of its life cycle. Environ. Exp. Bot. 20: 73-85.

Blum, U. and D.T. Tingey 1977. A study of the potential ways in which ozone could reduce root growth and nodulation of soybean. Atmos. Environ. 11: 737-739.

Blum, U., A.S. Heagle, J.C. Burns and R.A. Linthurst 1983a. The effects of ozone on fescue-clover forage: Regrowth, yield and quality. Environ. Exp. Bot. 23: 121-132.

Blum, U., E. Mrozek Jr. and E. Johnson 1983b. Investigation of ozone (O_3) effects on ^{14}C distribution in ladino clover. Environ. Exp. Bot. 23: 369-378.

Blum, U., G.R. Smith and R.C. Fites 1982. The effect of multiple O_3 exposure on carbohydrate, mineral content of ladino clover. Environ. Exp. Bot. 22: 143-154.

Bolla, R.I. and K. Fitzsimmons 1988. Effect of simulated acid rain on Bursaphelenchus xylophilus infection of pine seedlings. J. Nematol. 20: 590-598.

Bonte, J.L., Decormis and P. Lougvet 1977. Inhibition, en anerobiose, de la Reaction de permeture des Stomates du Pelargonium en Prescence de Dioxide de soufre. Environ. Pollut. (A) 12: 125-132.

Bopaiah, B.H., R.B. Patil and D.D.R. Reddy 1976. Effect of Meloidogyne javanica on nodulation and symbiotic nitrogen fixation in mung (Vigna radiata). Ind. J. Nematol. 6: 124-130.

Boralkar, D.B. and D.B. Shindhe 1983. Effects of sulphur dioxide and Ozone singly and in combination on germination and chlorophylls of Abelmoschus esculentus var. Pusa Sawani. J. Environ. Biol. 4: 99 - 102.

Borka, G. 1980. The effect of cement dust pollution on growth and metabolism of Helianthus annuus. Environ. Pollut. (A) 22: 75-79.

Brandt, C.S. and W.W. Heck 1968. Effects of air pollutants on plants. In: Air pollution (Ed. A.S. Stern) vol.1, pp. 401-443. Academic Press, New York.

Brennan, E. 1975. On exclusion as the mechanism of ozone resistance in virus infected plants. Phytopathology 65: 1054-1055.

Brewer, P.F. and A.S. Heagle 1983. Interaction between Glomus geosporum and exposure of soybeans to ozone or simulated acid rain in the field. Phytopathology 73: 1035-1040.

Bruck, R.I. and Shafer, S.R. 1984. Effects of acid precipitation on plant diseases. In: Direct and indirect effects on acidic deposition on vegetation (Ed. R.A. Linthurst) pp. 19-32. Butterworth Pub., Stoneham M.A.

Burton, J.C. 1979. New developments in inoculation legumes. In: Recent advances in biological nitrogen fixation (Ed. N.S. Subba Rao) pp. 380-405. Oxford and IBH Publishing Co., New Delhi, Bombay, Calcutta.

Butler, L.K. and T.W. Tibbitts 1979. Stomatal mechanisms determining genetic resistance to ozone in Phaseolus vulgaris L. J. Am. Soc. Hort. Sci. 104: 213-216.

Carlson, R.W. 1983. Interaction between SO_2 and NO_2 and their effects on photosynthetic properties of soybean, Glycine max. Environ. Pollut. (A) 32: 11-38.

Chopra, S.L. and J.S. Kanwar 1976. Analytical Agricultural Chemistry. Kalyani Publishers, New Delhi. 225 pp.

Clarke, B.B., M.R. Henninger and E. Brennan 1983. An assessment of potato losses caused by oxidant air pollution in New Jersey. Phytopathology 73: 104-108.

Cogwill, C.V. and G.E. Likens 1974. Acid precipitation in the north eastern United States. Water Resour. Res. 10: 1133-1137.

Colwill, D.M., J.R. Thompson and A.J. Rutter 1979. Impact of road traffic on plants. Crowthorne, Berks, Dept. of Env. Dept. of Transport, T.R.R.L. Report SR 513.

Couey, H.M. 1965. Inhibition of germination of Alternaria spores by sulfur dioxide under various moisture conditions. Phytopathology 51: 815-819.

Couey, H.M. and M. Uota, 1961. Effect of concentration, exposure time, temperature and relative humidity on the toxicity of sulfur dioxide to the spore of Botrytis cinerea. Phytopathology 51: 815-819.

Cowling, E.B. 1982. Acid precipitation in historical perspective. Environ. Sci. Technol. 16: 110A-123A.

Cowling, E.B. and J.G. Horsfall 1979. Prologue: How pathogens induce disease. In: Plant disease- An advanced treatise (Eds. J.G. Horsfall and E.B. Cowling) vol. IV, pp. 1-21. Academic Press New York.

Craker, L.E. 1972. Influence of ozone on RNA and protein content of Lemna minor L. Environ. Pollut. (A) 3: 319-323.

Craker, L.E. and J.S. Starback 1972. Metabolic changes associated with ozone injury in bean leaves. Can. J. Plant Sci. 52: 589-597.

Czech, M. and W. Northdurft 1952. Untersuchungen uber Schadigungen land wirtschftlicher und gartnerischer kulturp flangen durch chlor-Nitrose and Schwefeldioxydgase. Landwirtsch. Forsch. 4: 1-76.

Daines, R.H. 1968. Sulfur dioxide and plant response. J. Occupational Med. 10: 84-92.

Darley, E.F. 1966. Studies on the effect of cement kiln dust on vegetation. J. Air Pollut. Contr. Assoc. 16: 145-150.

Darley, E.F. and J.T. Middleton 1966. Problems of air pollution in plant pathology. Ann. Rev. Phytopathol. 4: 18-103.

Das, T.M. 1986. Editorial: International air pollution workshop at Chicago, Illinois, USA. Indian Biologist 18: 45-46.

Davis, D.D. and S.H. Smith 1974a. Reduction of ozone sensitivity of pinto bean by virus induced local lesions. Plant Dis. Rep. 60: 31-34.

Davis, D.D., and S.H. Smith 1974b. Reduction of ozone sensitivity of pinto bean by bean common mosaic virus. Phytopathology 64: 383-385.

Devlin, R.M. 1975. Plant Physiology, III edition. Affiliated East-West Press Pvt. Ltd., New Delhi, Madras, Hyderabad. 600 pp.

Donney, D.L. J.M. Fife and E.D. Whitney 1970. The effects of sugarbeet nematode Heterodera schachtii on the free amino acids in resistant and susceptible Beta species. Phytopathology 60: 1727-1729.

Dropkin, V.H. 1980. Introduction to Plant Nematology. John Wiley and Sons, New York. 293 pp.

Druzia, V.D., E.D. Miroshrachenko and O.D. Chertov 1983. Effects of industrial pollution on nitrogen and ash content in meadow phytocenotic plants. Bot. Zh. 68: 1583.

Edongali, E. and L. Ferris 1980. Effects of salinity and Meloidogyne incognita infection on the distribution of sdium (Na^+), potassium (K^+) and chloride (Cl^-) in tomatoes. Agr. Libyan J. A r. 9: 115-121.

Eisenback, J.D., H. Hirschmann, J.J. Sasser and A.C. Triantaphyllou 1981. A Guide to the Four Most Common Species of Root-knot Nematodes (Meloidogyne species). A Cooperative Publication of the Department of Plant Pathology and Genetics, North Carolina State University and the United States Agency for International Development Raleigh, N.C. 48 pp.

Elkan, G.H. 1984. Taxonomy and metabolism of Rhizobium and its genetic relationship. In: Biological nitrogen fixation - Ecology, technology and physiology (Ed. M. Alexander) pp. 1-38. Plenum Press, New York and London.

Elkiey, T. and D.P. Ormrod 1979. Leaf diffusion resistance responses of three petunia cultivars to ozone and/or sulphur dioxide. J. Air Pollut. Contr. Assoc. 29: 622-625.

Eller, B.M. 1977. Road dust induced increase of leaf temperature. Environ. Pollut. (A) 13: 99-107.

Elseevi, A.A., S.R. Grimm, A.L. Page and I.R. Straughan 1981. Boron enrichment of plants and soils treated with coal flyash. J. Plant Nutr. 3: 409-427.

Engle, R.L. and W.H. Gabelman 1966. Inheritance and mechanism of resistance to ozone damage to onion, Allium cepa L. Proc. Am. Soc. Hort. 89: 423-430.

Epps, J.M. and A.Y. Chambers 1962. Nematode inhibits nodules on soybeans. Crops and Soils 15: 18.

Erdman, L.W. and U.M. Means 1952. Use of total yield for predicting nitrogen content of inoculated legumes grown in sand cultures. Soil Sci. 73: 231-235.

Evans, L.S. 1982. Biological effects of acidity in precipitation on vegetation. Environ. Expt. Bot. 22: 155-169.

Evans, L.S. 1988. Effect of acidic deposition on vegetation: State of science. In: Perspective in environmental botany (Eds. D.N. Rao, K.J. Ahmad, M. Yunus and S.N. Singh) vol. 2, pp. 73-119. Today and Tomarrow's Printers and Publishers, New Delhi.

Evans, L.S., K.F. Lewin, C.A. Conway and H.J. Patti 1981. Seed yields (quantity and quality) of yield grown soybeans exposed to simulated acidic rain. New Phytol. 89: 459-470.

Evans, L.S., K.F. Lewin, M.J. Patti and E.A., Cunnigham 1983. Productivity of field-grown soybeans exposed to simulated acidic rain. New Phytol. 93: 377-388.

Eveling, D.W. 1969. Effect of spraying plants suspensions of inert dusts. Ann. Appl. Biol. 64: 139-151.

Fahn, A. 1982. Plant Anatomy (III edition). Pergamon Press, Oxford, New York, Torant, Sydney, Paris, Frankfurt.

Fluckiger, W., H. Fluckger-Keller and J.J. Oertli 1978. Der Einfluss von strassentaub auf den stomataren effekt. Staub. Reinhalt Luft 38: 502-505.

Fluckiger, W., J.J. Oertili and H. Fluckiger 1979. Relation between stomatal diffusive resistance and various

applied particle size on leaf surface. Z. Pflanzenphysiol. 91: 173-175.

Foster, K.W., H. Timm, C.K. Labanauskas and R.J. Oshima 1983. Effects of ozone and sulphur dioxide on tuber yield and quality of potatoes. J. Environ. Qual. 12: 75-79.

Fred, E.B., I.L. Baldwin and E. McCoy 1932. Root nodule bacteria and leguminous plants. Studies in Science, No. 5, pp. 343. University of Wisconsin Press, Madison.

Freire, J.R.J. (1984) Important limiting factors in soil for the Rhizobium - legume symbiosis. In: Biological nitrogen fixation - Ecology, technology and physiology (Ed. M. Alexander) pp. 51-74. Plenum Press, New York and London.

Fruton, J.S. and S. Simmonds 1959. General Biochemistry. John Wiley and Sons, New York.

Fuhrer, J. and K.H. Erismann 1980. Uptake of NO_2 by plants grown at different salinity levels. Experientia 36: 409-410.

Gesalman, C.M. and D.D. Davis 1978. Ozone susceptibility of ten azalea cultivars as related to stomatal frequency or conductance. J. Am. Soc. Hort. Sci. 103: 489-491.

Ghouse, A.K.M. and A.Z. Amani 1978. Effect of air pollution on fruit formation and seed setting in Dalbergia sissoo. Proc. Int. Symp. Environmental agents and their biological effects. Aligarh. pp. 120-124.

Ghouse, A.K.M. and A.U. Khan 1978. Environmental pollution and epidermal structure in Psidium guajava L. Proc. Int. Symp. Environmental agents and their biological effects. Aligarh pp. 41-44.

Ghouse, A.K.M. and M. Yunus 1972. Preparation of epidermal peels from leaves of gymnosperms by treatment with hot 60% HNO_3. Stain Technol., 47: 322-324.

Grahn, O., H. Hultberg and L. Landner 1974. Oligotrophication a self aculerating process in lakes subjected to excessive supply of acid substances. Ambio 3: 93-94.

Grunwald C. and A.H. Endress 1984. J. Agric. Chem. 32:50. Cited by Heck, W.W., A.S. Heagle and D.S. Shriner 1986. Effects on vegetation: Native, crops, forests. In: Air pollution (Ed. A.S. (Stren) vol. 6, pp. 247-350. Academic Press New York.

Gudarian R., H. Van Hunt and H. Stratman 1960. Problems of the recognition and evaluation of the effect of gaseous air impurities on vegetation. Z. Pflanzen-krankh. Pflanzenschutz 67: 257-264.

Gupta, M.C. 1981. Growth and reproductivity of certain vegetable crops in relation to air pollution around Kasimpur Thermal Power Station, Ph.D. Thesis, Aligarh Muslim University, Aligarh India.

Gupta, M.C. and A.K.M. Ghouse 1987a. The effects of coal-smoke pollutants on the growth, yield and leaf epidermal features of Abelmoschus esculentus Moench. Environ. Pollut. 43: 263-270.

Gupta, M.C. and A.K.M. Ghouse 1987b. The coal-smoke pollutants from different sources on the growth, chlorophyll content, stem anatomy and cuticular traits of Euphorbia hirta L. Environ. Pollut. 47: 221-229.

Ham, D.L. 1971 The biological interactions of sulfur dioxide and Scirrhia acicola on loblolly pine. Ph.D. Thesis, Duke University, Durham, N.C. 74 pp.

Haines, B., J. Chapman and C.D. Monk 1985. Rates of mineral element leaching from leaves of nine plant species from a southern Appalachian forest succession subjected to simulated acid rain. Bull. Torrey Bot. Club. 112: 258-264.

Harris, M.J. and R.L. Heath 1981. Ozone sensitivity in sweet corn (Zea mays L.) plants: A possible relationship to water balance. Plant Physiol. 68: 885-890.

Heagle, A.S. 1970. Effect of low level ozone fumigations on crown rust of oats. Phytopathology 60: 252-254.

Heagle, A.S. 1973. Interactions between air pollutants and plants parasites. Ann. Rev. Phytopathol. 11: 365-388.

Heagle, A.S. 1977. Effect of ozone on parasitism of corn by Helminthosporium maydis. Phytopathology 67: 616-618.

Heagle, A.S. 1982. Interaction between air pollutants and parasitic plant disease. In: Effects of gaseous air pollution in agriculture (Eds. M.H. Unsworth and D.P. Ormrod) pp. 333-348. Butterworth Scientific Publishers, London.

Heagle, A.S. and J.W. Johnston 1979. Variable responses of soybeans to mixtures of ozone and sulphur dioxide. J. Air Pollut. Contr. Assoc. 29: 729-732.

Heagle, A.S. and L.W. Key 1973. Effect of ozone on the wheat stem rust fungus. Phytopathology 63: 397-400.

Heath, R.L. 1975. Ozone. In: Responses of plants to air pollution (Eds. J.B. Mudd and T.T. Kozlowski) pp. 23-25. Academic Press, New York.

Heath, R.L. 1980. Initial events in injury to plants by air pollutants. Ann. Rev. Plant Physiol. 31: 395-431.

Heath, R.L. and E. Frederick, 1979. Ozone alteration of membrane permeability in Chlorella. Plant Physiol. 64: 455-459.

Heck, W.W. 1968. Factors influencing expression of oxidant damage to plants. Ann. Rev. Phytopathol. 6: 165-188.

Heck, W.W. 1982. Future directions in air pollutant research In: Effects of gaseous air pollution in agriculture and horticulture. (Eds. M.H. Unsworth and D.P. Ormrod) pp. 411-436. Butterworth Scientific Publishers, London.

Heck, W.W. and S.B. MacLaughlin 1986. Effects of gaseous air pollutants on terrestrial vegetation. In: Pollutant and their effects on the terrestrial ecosystem. (Eds. A.L. Legge and S.V. Krupa) pp. 325-338. John Wiley and Sons, New York.

Heck, W.W., R.H. Daines and I.J. Hindawi 1970. Other phytotoxic pollutants. In: Recognition of air pollution injury to vegetation: A pictorial atlas (Eds. J.S. Jacobson and A.C. Hill) pp. F1-F24. Air Pollut. Contr. Assoc. Pittsburgh, Pennsylvania, U.S.A.

Heck, W.W., A.S. Heagle and D.S. Shriner 1986. Effects on vegetation: Native, crops, forests. In: Air pollution Ed. A.S. Stern) vol. 6, pp. 247-350. Academic Press, New York.

Helder, T., E. Stutterheim and K.Olie 1982. The toxicity and toxic potential of flyash from municipal incenerators assessed by means of a fish early life stage test. Chemosphere 11: 965-972.

Henderson, W.R. and R.A. Reinert 1979. Yield response of four fresh market tomato cultivars after acute ozone exposure in the seedling stage. J. Am. Soc. Hort. Sci. 104: 754-759.

Hibben, C.R. 1966. Sensitivity of fungal spores to sulphur dioxide and ozone. Phytopathology 56: 880.

Hibben, C.R. and G. Stotzky 1969. Effects of ozone on the germination of fungus spores. Can. J. Microbiol. 15: 1187-1196.

Hibben, C.R. and M.P. Taylor 1975. Ozone and sulphur dioxide effects on the lilac powdery mildew fungus. Environ. Pollut. (A) 9: 107-114.

Hill, A.C. and N. Littlefield 1969. Ozone effect on apparent photosynthesis, rate of transpiration, stomatal closure in plants. Environ. Sci. Technol. 3: 52-56.

Hill, A.C., M.R. Pack, M. Treshow, R.F. Downs and L.G. Transtrum 1961. Plant injury induced by ozone. Phytopathology 51: 356-368.

Horsman, D.C. and A.R. Wellburn 1977. Effect of SO_2 polluted upon enzyme activity in plants originating from areas with different annual mean atmospheric SO_2 concentrations. Environ. Pollut. (A) 13: 33-38.

Howell, R.K. and D.F. Kremer 1973. The chemistry and physiology of pigmentation in leaves injured by air pollution J. Environ. Qual. 2: 434-438.

Hua, Y. and P. Wang 1987. Effects of simulated acid rain on rice during its growing season. Huanjing Kexue 8:25-27.

Huang, J.S. 1987. Interaction of nematodes with rhizobia. In: Vistas on nematology (Eds. Veech, J.A. and Dickson, D.W.) pp. 301-306. Society of Nematologist Inc., Hyattsville, Maryland.

Huang, J.S. and and K.R. Barker 1983. Influence of Heterodera glycines on leghaemoglobins of soybean nodules. Phytopathology 73: 1002-1004.

Hussaini, S.S. and A.R. Seshadri 1975. Interrelationships between Meloidogyne incognita and Rhizobium sp. on mung bean (Phaseolus aureus). Ind. J. Nematol. 5: 189-199.

Hussey, R.S. 1985. Host-parasite relationships and associated physiological changes. In: An advanced treatise on Meloidogyne, vol I: Biology and control (Eds. J.N. Sasser and C.C. Carter) pp. 143-153. A cooperative publication of the Department of Plant Pathology and the USAID.

Hussey, R.S. and K.R. Barker 1976. Influence of nematodes and light sources on growth and nodulation on soybean. J. Nematol. 8: 48-52.

Hyde, E.O. 1954. The function of the hilum in some papilionaceae in relation to the ripening of the seed and permeability of the testa. Ann. Bot. 18: 241.

Ichimohe, M. 1961. Studies on soybean cyst nematode, Heterodera glycines. Rep. Hokkaido Nat. Agr. Expt. Sta. 56: 80.

Ingram, M. and R.B. Haines 1949. Inhibition of bacterial growth by pure O_3 in the presence of nutrients. J. Hyg. 47: 146-158.

Irving, P.M. and J.E. Miller 1984. Synergistic effect on field grown soybeans from combinations of sulphur dioxide and nitrogen dioxide. Can. J. Bot. 62: 840-846.

Jackson, M.L. 1958. Soil Chemical Analysis. Constable and Co. Ltd. London. 375 pp.

Jacobson, J.S. and L.J. Colavito, 1976. The combined effect of sulphur dioxide and ozone on bean and tobacco plants. Environ. Exp. Bot. 15: 277-285.

Jacobson, J.S. and A.C. Hill 1970. Recognition of Air Pollution Injury to Vegetation: A Pictorial Atlas. Air Pollution Control Association, Pittsburg, Pensylvana, U.S.A.

James, R.L., F.W. Cobb Jr., P.R. Miller and J.R. Parmeter Jr. 1980. Effects of oxidant air pollution on susceptibility of pine roots to Fomes annosus. Phytopathology 80: 560-563.

Jensen, H.L. 1942. Nitrogen fixation in leguminous plants. I. General characters of root nodule bacteria isolated from species of Medicago and Trifolium in Australia. Proc. Linn. Soc. N.S.W. 67: 98-108.

Jensen, K.F. 1981. O_3 fumigation decreased the root carbohydrate content dry weight of green ash seedlings. Environ. Pollut. (A) 26: 147-152.

Jones, D.G. and I.R. Straughan 1978. Impact of solid discharges from coal usage in the south-west. Environ. Health Perspect. 27: 275-281.

Jordan, D.C. 1982. Transfer of Rhizobium japonicum Buchaman 1980 to Bradyrhizobium gen. nov., a genus of slow growing. root nodule bacteria from leguminous plants. Int. J. System. Bact. 32: 136-139.

Kamath, R.R. 1979. Trace elements concentrations in coal and corresponding flyash. Ind. J. Air Pollut. Contr. 2 : 91-95.

Khan, M.W. 1984. Ecological niche of plant nematodes in soil biotic community. In: Progress in microbiol ecology (Eds. K.G. Mukerji, V.P. Agnihotri and R.P. Singh) pp. 165-177. Print House (Inida), Lucknow

Khan, A.A. and S.S. Malhotra 1983. Protein biosynthesis in jack pine and its inhibition by sulphur dioxide. Phytochemistry 22: 1325-1328.

Khan, M.R., S.K. Singh and M.W. Khan 1987. Effect of nickel on growth of lentil plants. Indian Assoc. Water Pollut. Contr.,Tech. Ann. 14: 57-60.

Khan, M.R., S.K. Singh and M.W. Khan 1988. Response of lentil to cobalt as a soil pollutant. Test of Agrochem.9, Ann. Appl.Biol. (Suppl.) 112: 104-105.

Klarer, C.I., R.A. Reinert and J.S Huang 1984. Effects of sulphur dioxide and nitrogen dioxide on vegetative growth of soybeans. Phytopathology 74: 1104-1106.

Kobriger, J.M., T.W. Tibbits and M.L. Brenner 1984. Injury, stomatal conductance and abscisic acid levels of pea plants following ozone plus sulphur dioxide exposures at different times of the day. Plant Physiol. 76: 823-826.

Kondo, N. and K. Sugahara 1978. Changes in transpiration rate of SO_2 resistant and sensitive plants with SO_2 fumigation and the participation of abscisic acid. Plant Cell Physiol. 19: 365-373.

Kozial, M.J. and C.F. Jordon 1978. Changes in carbohydrate levels in red kidney bean (Phaseolus vulgaris L.) exposed to sulphur dioxide. J. Exp. Bot. 29: 1037-1044.

Kress, L.W., J.E. Miller, H.J. Smith and J.O. Rawlings 1986. Impact of ozone and sulphur dioxide on soybean yield. Environ. Pollut. (A) 41: 105-123.

Kumar, N. 1986. Response of Vigna radiata to SO_2 and NO_2 pollution. Acta Botanica Indica 14: 139-144.

Lauenorth, W.K. and J.L. Dodd 1981. Chlorophyll reduction in western wheat grass (Agropyron smithii Rydb.) exposed to sulphur dioxide. Water, Air, Soil Pollut. 15: 309.

Laurence, J.A. 1979. Response of maize and wheat to SO_2. Pl. Dis. Rep. 63: 468-471.

Laurence, J.A. and A.L. Aluisio 1981. Effects of sulphur dioxide on expansion of lesions caused by Corynebacterium nebraskense in maize and by Xanthomonas phaseoli var. sojensis in soybean. Phytopathology 71: 445-448.

Laurence, J.A. and F.A. Wood 1978a. Effects of ozone on infection of soybean by Pseudomonas glycines. Phytopathology 68: 441-445.

Laurence, J.A. and F.A. Wood 1978b. Effect of ozone on infection of wild strawberry by Xanthomonas fragariae. Phytopathology 68: 689-692.

Laurence, J.A., A.L. Aluisio, L.H. Weinstein and D.C. Mc Cune 1981. Effects of sulphur dioxide on southern bean mosaic and maize dwarf mosaic. Environ. Pollut. (A) 24: 185-191.

Laurence, J.A., L.H. Weinstein, D.C. Mc Cune and A.L. Aluisio, 1979. Effects of sulphur dioxide on southern corn leaf blight of maize and stem rust of wheat. Plant Dis. Rep. 63: 975-978.

Leckowicz, H.J. 1987. Resource allocation by plants under air pollution stress. Implications for plant-pest-pathogen interaction. Bot. Rev. 53: 281-300.

Ledbetter, M.C., P.W. Zimmerman and A.E. Hitchcock 1959. The histopathological effects of ozone on plant foliage. Contrib. Boyce Thompson Inst. 20: 275-282.

Lehman, P.S., D. Huising and K.R. Barker 1971. The influence of races of Heterodera glycines on nodulation and nitrogen fixing capacity of soybean. Phytopathology 61: 1239-1244.

Letchworth, M.B. and U. Blum 1977. Effects of acute ozone exposure on growth, nodulation and nitrogen content of ladino clover. Environ. Pollut. (A) 14: 303.

Lewis, S.A. 1987. Nematode-plant compatibility. In: Vistas on nematology (Eds. J.A. Veech and D.W. Dickson) pp. 246-252. Nematologists Inc., Hyattsville, Maryland, U.S.A.

Likens G.E. and F.H. Bormann 1974. Acid rain: A serious regional environmental problem. Science 184: 1176-1179.

Linzon, S.N. 1958. The influence of smelter fumes on the growth of white pine in the Sudbury region. Can. Dep. Agr. Pub., Ontaria Dep. Lands. Forests. 45 pp.

Linzon, S.N. 1978. Effect of air sulphur pollutants on plants. In: Sulphur in environment (Ed. J.O. Nriagu) pp. 109-162. John Wiley and Sons, New York.

Lockyar, D.R. and D.W. Cowling 1981. Growth of lucerne (Medicago sativa L.) exposed to sulphur dioxide. J. Exp. Bot. 32: 1333-1341.

Lotstein R.J., D.D. Davis and E.J. Pell 1983. Hort. Sci. 18: 72. Cited by Heck W.W., A.S. Heagle and D.S. Shriner. Effects on vegetation: native, crops, forests. In: Air pollution (Ed. A.S. Stern) vol. 6, pp. 246-350. Academic Press, New York.

Lowry, O.H., N.J. Rosebrough, A.L. Farr, and R.J. Randall 1951. Protein measurement with follin phenol reagent. J. Biol. Chem. 193: 265-275.

Macdowall, F.D.H. 1965. Stages of ozone damage to respiration of tobacco leaves. Can. J. Bot. 43: 419-427.

Mackinney, G. 1941. Absorption of light of chlorophyll solution. J. Biol. Chem. 140: 315-322.

Mac Lean, D.C. McCune, L.H. Weinstein, R.H. Mandl and G.N. Woodruff 1968. Effects of acute HF and NO_2 exposure on citrus and ornamental plants of central Florida. Environ. Sci. Tech. 2:444-449.

Majernik, O. and T.A. Mansfield 1970. Direct effect of sulphur dioxide pollution on the degree of opening of stomata. Nature 227: 377-378.

Malek, R.B. and W.R. Jenkins 1964. Aspects of host parasite relationships of nematodes and hairy vetch. Bull. N.J. Agr. Expt. Sta. Bull. No. 813: 31.

Manning, W.J. and W.A. Feder 1976. Effects of ozone on economic plants. In: Effects of air pollutants on plants (Ed. T.A. Mansfield). Soc. Exp. Bio. Semin. Ser. No.1, pp. 47-60.

Mark, L.T. 1963. Temperature inhibition of carotene synthesis in tomato. Bot. Gaz. 124: 180-185.

Masefield, G.B. 1958. Some factors affecting nodulation in tropics. In: Nutrition of the legumes (Ed. E.G. Hallsworth) pp 203-215. Academic Press, New York and London.

Mass, E.V., G.J. Hoffman, S.L. Rawlins and G. Ogata, 1973. Salinity - ozone interactions in pinto bean:Integrated response to ozone concentrations and duration J. Environ Qual. 2: 400-404.

McCallan, S.E.A. and F.R. Weedon 1940. Toxicity of ammonia, chlorine, hydrogen cyanide, hydrogen sulphide and sulphur dioxide gases. II. Fungi and bacteria. Contrib. Boyce Thompson Inst. 11: 331-342.

McLaughlin,S.B.,D.S.,Shriner, R.K. McConthy and L.K. Mann. 1979. The effects of SO_2 dosage, kinetics and exposure frequency on photosynthesis and transpiration of kidney bean (Phaseolus vulgaris L.). Environ. Exp. Bot. 19: 179-191.

Mejestrick, V. 1980. The influence of low SO_2 concentration on growth reduction of Nicotiana tabacum L. cv. Samsum and Cucumis sativus L. cv. Unikat. Environ. Pollut (A) 21: 73.

Middleton, J.T., E.F. Darley and R.F. Brewer 1958. Damage to vegetation from polluted atmospheres. J. Air. Pollut Contr. Assoc. 8: 9-15.

Miller, J.E. 1987. Effects of ozone and sulphur dioxide stress on growth and carbon allocation in plants. In: Phytochemical effects of environmental compounds (Eds. J.A. Saunder, L. Kosak-Channing and E.E. Conn) pp. 55-100. Plenum Press, New York.

Mishra, L.C. 1980. Effects of SO_2 fumigation on groundnut. Environ. Exp. Bot. 20: 397-400.

Mishra , L.C. and K.N. Shukla 1986. Effects of flyash deposition on growth, metabolism and dry matter production of maize and soybean. Environ. Pollut. 42(A):1-13.

Moriarty, F. 1962. The effect of sowing time and of nitrogen on peas, Pisum sativum and in pea root eelworm, Heterodera gottingiana Leibscher. Nematologica 8: 169-175.

Mudd, J.B. and T.T. Kozlowski 1975. Responses of Plants to Air Pollution. Academic Press, New York. 383 pp.

Munns, D.N., R.L. Fox and B.L. Koch 1977. Influence of lime on nitrogen fixation by tropical and temperate legumes. Plant and Soil 45: 591-601.

Nandi, P.K., M. Singh and D.N. Rao 1980. Effect of ozone, sulphur dioxide and their mixture on organization of Phaseolus aureus seed. Ind.J.Air Pollut.Contr. 3:50-55.

Negherborn, W.O. 1966. Sulfur dioxide, sulfur trioxide and flyash: Their nature and their role in air pollution. EEI Research Project RP62, Edison Electric Institute, New York.

Nieboer, E., D.H.S. Richardon, K.J. Puckett, and F.O. Tomassini 1976. Phytotoxicity of sulphur dioxide in relation to measureable response in lichens. In: Effects of air pollutants on palnts (Ed. T.A., Mansfield) pp. 61-86. Cambridge Press. Cambridge, England.

Nigh, E.L. Jr. 1966. Rhizobium nodule formation on alfalfa as influened by Meloidogyne javanica. Nematologica 12: 96 (Abst.).

Nutman, P.S. 1958. The physiology of nodule formation. In: Nutrition of the legumes (Ed. E.G. Hallsworth) pp. 87-107. Academic Press, New York.

O'Bannon, J.H. and H. W. Reynolds 1961. Root-knot nematode damage and cotton yields in relation to certain soil properties. Soil Sci. 92: 354-386.

Oden, S. 1968. The acidification of air and precipitation and its consequences in the natural environment. Bull No. 1, Ecology committee, Swedish National Science Research Council Stockholm.

Olszyk, D.M. and C.R. Thompson 1985. Effects of air pollutants on important grain and legume field crops: Applicability to tropical areas. In: Perspectives in environmental botany (Eds. D.N. Rao, K.J. Ahmad, M. Yunus and S.N. Singh) vol. I, pp. 151-174. Print House (India) Lucknow.

Olszyk, D.M. and T.W. Tibbits 1981a. Stomatal response and leaf injury of Pisusm sativum L. with SO_2 and O_3 exposures. I. Influence of pollutant level and leaf maturity. Plant Physiol. 67: 539-544.

Olszyk, D.M. and T.W. Tibbitts 1981b. Stomatal response and leaf injury of Pisum sativum L. with SO_2 and O_3 exposures II. Influence of moisture stress and time of exposure. Plant Physiol. 67: 545-549.

Olszyk, D.M. and T.W. Tibbits 1982. Evaluation of injury to expanded and expanding leaves of peas exposed to sulphur dioxide and ozone. J. Am. Soc. Hort. Sci. 107: 266-271.

Ormrod, D.P., D.T. Tingey and M. Gumpertz 1983. Covariate measurements for increasing the precision of plant response to O_3 and SO_2. Hort. Sci. 18: 896-898.

Oshima, R.J., P.K. Braegelmann, D.W. Baldwin, V.Van Way O.C. Taylor 1977a. Reduction of tomato fruit size and yield by ozone. J. Am. Soc. Horti. Scie. 102: 289-293.

Oshima, R.G., P.K. Braegelmann, D.W. Baldwin, V.Van Way and O.C. Taylor 1977b. Responses of five cultivars of fresh market tomato to ozone a contrast of cultivar screening with foliar injury and yield. J. Am. Soc. Horti. Sci. 102: 286-289.

Osiima, R.J. P.K. Braegelmann, R.B. Flagler and R.R. Teso 1979. Effects of ozone on the growth, yield and partitioning of dry matter in cotton. J. Environ. Qual. 8: 474-479.

Oteifa, B.A. 1953. Development of root-knot nematode, Meloidogyne incognita, as affected by potassium nutrition of the host. Phytopathology 43: 171-174.

Paleg, L.G. 1960b. Physiological effects of gibberellic acid. I. On carbohydrate metabolism and amylase activity of barley endosperm. Plant Physiol. 35: 293.

Paleg, L.G. 1960b. Physiological effects of gibberrellic acid. II. On starch hydrolyzing enzymes of barley endosperm. Plant Physiol. 35: 902.

Pandey, S.N. and D.N. Rao 1987. Effects of coal smoke and sulphur dioxide pollution on the accumulation of certain minerals and chlorophyll contents of wheat plants. Trop. Ecol. 19: 155-162.

Pell, E.J. and E. Brennan 1973. Changes in respiration, photosynthesis, adenosin 5-triphosphate and total adenylate content of ozonated pinto bean foliage as they relate to symptom expression. Plant Physiol. 51: 379-381.

Pell, E.J. and M. Puente, 1987. Impact of simulated acid rain on yield of a field-grown oat crop. Environ. Exp. Bot. 27: 403-407.

Pell, E.J., W.C. Weissberger and J.J. Sperioni 1980. Impact of ozone on quantity and quality of greenhouse grown potato plants. Environ. Sci. Technol. 14: 568-571.

Perrin, P. 1970. Oroganisation intrastructural, en rapport avec les processus de secretion, des poils glandulaires (trichome-hydathodes) de Phaseolus multiflorus. C.P. Acad. Sc. (Paris) 270: 1984-1987.

Pierre, M. and O Quiroz 1952. Modulation leaf age and SO_2 concentration of the enzymatic response to subnecrotic SO_2 pollution. Environ. Pollut. (A) 28 : 209-217.

Plesnicar, M. 1983. Study of sulphur dioxide effects on phosphorus metabolism in plants using ^{32}P as indicator. Int. J. Appl. Radiat. Isot. 34: 833-836.

Porter, P.M., W.L. Bonwart, J.J. Hassett, and R.L. Finke 1987. Effect of simulated acid rain on yield response of two soybean cultivars. J. Environ. Qual. 16 : 433-437.

Powell, N.T. 1971a. Interaction between nematodes and fungi in disease complexes. Ann. Rev. Phytopathol. 9: 253 274.

Powell,N.T. 1971b. Interaction plant parasitic nematodes with other disease-causing agents. In: Plant parasitic nematodes (Eds. B.M. Zuckerman, W.F. Mai and R.A. Rohde) vol. II, pp. 119-136.

Pratt,G.C.,K.W. Kromroy and S.V. Krupa 1983. Effect of ozone and sulphur dioxide on injury and foliar concentrations of sulphur and chlorophyll in soybean Glycine max. Environ. Pollut. (A) 32: 91-99.

Rai, B. and K.K. Pathak 1981. Studies on phylloplane microflora of potato in relation to air pollutants. Environ. Pollut. (A) 26: 153-166.

Rao, D.N. 1971. A study of the air pollution problem due to coal unloading in Varanasi, India. Proc. Int. Clean Air Congr. 2nd ed. (Eds. H.M. England and W.T. Beert) pp. 270-273. Academic Press, New York.

Rao, D.N. and F. LeBlanc 1966. Effects of SO_2 on the lichen algae with special reference to chlorophyll. Bryologist 69: 69-75.

Reinert, R.A. 1984. Plant response to air pollutant mixture. Ann. Rev. Phytopathol. 22: 421-442.

Reinert, R.A. and G.V. Gooding Jr. 1978. Effect of ozone and tobacco streak virus alone and in combination on Nicotiana tabacum. Phytopathology 68: 15-17.

Reinert, R.A. and D.E. Weber 1980. Ozone and sulphur dioxide induced changes in soybean growth. Phytopathology 70: 914-916.

Reinert, R.A., H.E. Heggested and W.W. Herb 1982. Response and genetic modification of plants for tolerance to air pollutants. In: Breeding plants for less favourable environments (Ed. Dr. Christionsen) pp. 259-292. John Wiley and Sons, USA.

Reinert, R.A., D.T. Tingey and C.E. Koons 1971. The early growth of soybean as influenced by ozone stress. Agron. Abstr. 63: 148.

Resh, H.M. and V.C. Runeckles 1973. Effects of ozone on bean rust Uromyces phaseoli. Can. J. Bot. 51: 725-727.

Rhoads, A and E. Brennan, 1978. The effect of ozone on chloroplast lamellae and isolated mesophyll cells of sensitive and resistant tobacco selections. Phytopathology 68: 883-886.

Ricks, G.R. and R.J. Williams 1974. Effects of atmospheric pollution on deciduous woodland. 2: Effects of particulate matter upon stomatal diffusion resistance in leaves of Quercus petraea (Mattuschka) Liebl. Environ. Pollut. (A) 6: 87-109.

Robinson, P.E. 1961. Root-knot nematode and leguminous nodules. Nature 189: 506-507.

Rosen, P.M., R.C. Musselman and W.J. Kender 1978. Relationship of stomatal resistance to sulphur dioxide and ozone injury in grapevines. Sci. Hort. 8: 137-142.

Sakaki, T., N. Kando and K. Sugahara 1985. Breakdown of photosynthetic pigments and lipids in spinach leaves with ozone fumigation: Role of active oxygens. Physiol. Plant. 59: 28.

Sasser, J.N. 1954. Identification and host-parasite relation ships of certain root-knot nematodes (Meloidogyne sp.).Md. Agric. Exp. Stn. Bull. A-77. 31 pp.

Sasser, J.N. 1980. Root-knot nematodes : A global meanace to crop production. Plant Dis. 64: 36-41.

Sasser, J.N. and C.C. Carter 1982. Overview of the International Meloidogyne Project - Rationale, goals implementation and progress to date. pp. 3-13. In: Proc. IMP Res. Plant Conf. Root-knot nematodes, Meloidogyne spp. (region III),Brasillia, Brazil.

Saunders, P.J.W. 1966. The toxicity of sulphur dioxide to Diplocarpon rosae Wolf causing black spot of roses. Ann. Appl. Biol. 58: 103-114.

Sawyer, T., S. Bandiera, S. Safe, O. Hutzinger and K. Olie 1983. Bioanalysis of polychlorinated dibenzofuran and dibenzo-p-dioxin mixture in flyash. Chemosphere 12: 529-536.

Saxe, H. 1983a. Long-term effects of low levels of SO_2 on bean plants (Phasoolus vulgaris).I. Immission-response pattern of net photosynthesis and transpiration during life-long, continuous measurements. Physiol. Plant. 57: 101-107.

Saxe, H. 1983b. Long-term effects of low levels of SO_2 on bean plants (Phaseolus vulgaris). II. Immission-response effects on biomass production: Quantity and quality. Physiol. Plant 57: 108-113.

Scheffer, T.C. and G.C. Hedgcock 1955.Injury to northwestern forest trees by sulphur dioxide from smelters. U.S.D.A. Tech. Bull. No. 1117, 49 pp.

Sharma, H.C. and D.N. Rao 1985. Responses of Phaseolus aureus plants to SO_2 and HF pollutants. In: Perspectives in environmental botany (Eds. D.N. Rao, K.J. Ahmad, M.Yunus and S.N. Singh) vol. I, pp. 133-150. Print House (India), Lucknow.

Sharma, N.K. and C.L. Sethı 1975. Leghaemoglobın content of cowpea nodules as ınfluenced by Meloıdogyne ıncognıta and Heterodera cajanı. Ind. J. Nematol. 45: 113-114.

Sharma, G.K., C. Chandler and L. Saılemı 1980. Envıronmental pollutıon and leaf cutıcular varıatıon ın kudzu (Pueraria lobata Wild.). Ann. Bot. 45: 77-80.

Sharp, E.L. 1967. Atmospherıc ıons and germınatıon of uredospores of Puccınia strıiformıs. Scıence 156: 1359-1360.

Shertz, R.D., W.J. Kender and R.C. Musselman 1980. Effects of ozone and sulphur dıoxıde on grapevınes. Scı. Hort. 13: 37-45.

Shew, B.B., R.A. Reınert and K.R. Barker 1982. Response of tomatoes to ozone, sulphur dıoxıde and ınfectıon by Pratylenchus penetrans. Phytopathology 72: 822-826.

Shımızu, H., S. Motohashı, H. Iwakı, A Furukawa and T. Totsuka 1981. Effect of chronıc exposure to ozone on the growth of sunflower plant. Envıron. Contr. Biol. 19: 137.

Shneff, E. 1965. Lıtch-und elektron mıkroskopesche Beobachtungen an den Trıchom-Hydatheden von Cicer arıetınum. Z. Pflanzenphysıol 53: 245-254.

Shrıner, D.S. 1978. Lffects of sımulated acıdıc raın on host parasıte ınteractıons ın plant dısease. Phytopathology 68: 213-218.

Shrıner, D.S. and J.W. Johnston 1981. Effects of stımulated acıdıfied raın on nodulatıon of leguminous plants by Rhızobıum sp. Envıron. Exp. Bot. 21: 199-209.

Sıkora, R.A. and W.W. Carter 1987. Nematode ınteractıon wıth fungal and bacterıal plant pathogens-fact or fantasy. In: Vıstas on nematology (Eds. J.A. Veech and D.W. Dıckson) pp. 307-312. Socıety of Nematologısts, Inc., Hyattsville, Maryland, USA.

Sıngh, S.N. and D.N. Rao 1981. Certaın responses of wheat plants to cement dust pollutıon. Envıron. Pollut. (A): 24: 75-81.

Skye, E. 1968. Lıchens and aır pollutıon. Acta Phytogeorgr. Suec. 52: 1-123.

Smith, M.E. 1968. The influence of atmospheric dispersion on the exposure of plants to air borne pollutants. Phytopathology 58: 1085-1088.

Soldatini, G.F. and I. Ziegler 1979. Induction of glycolate oxidase by SO_2 in Nicotiana tabacum. Phytochemistry 18: 21-22.

Sprugel, D.G., J.E. Miller, M.H. Smith and P.B. Xerikos 1980. SO_2 effects on yield and seed quality in field grown soybean. Phytopathology 70: 1129-1133.

Subba Rao, N.S. 1972. Rhizobia and nodulation. Curr. Sci. 41: 1-42.

Subba Rao, N.S. 1975. Soil Microorganisms and Plant Growth. Oxford and IBH Pub. Co. New Delhi, Bombay, Calcutta. 289 pp.

Suwannapinunt, W. and T.T. Kozlowsky 1980. Effect of sulphur dioxide on transpiration, chlorophyll content, growth and injury in young seedlings of woody angiosperms. Can. J. For. Res. 10: 78-81.

Taha, A.H.Y. and D.J. Raski 1969. Interrelationship between root-nodule bacteria, plant parasitic nematode and their leguminous host. J. Nematol. 1: 201-211.

Takemoto, B.K. and R.D. Noble 1982. The effects of short-term SO_2 fumigation on photosynthesis and respiration in soybean. Environ. Pollut. (A). 28: 67-74.

Tamm, C.O. and E.B. Cowling, 1977. Acid precipitation and and forest vegetation Proc. 1st Int. Symp. Acid precipitation and the forest ecosystem (Eds. L.S. Dochinger and T.A. Seliga). U.S.D.A., Northeastern Forest Experiment Station, Upper Darby, PA. 845 pp.

Tanaka, K., T. Totsuko and N. Kondo 1982. Participation of hydrogen per oxide in the inactivation of Calvin cycle SH enzyme SO_2 fumigated spinach leaves. Plant Cell Physiol. 23: 1009-1018.

Taylor, C.E. 1979. Meloidogyne interrelationships with microorganism In: Root-knot nematodes (Meloidogyne species) (Eds. F. Lamberti and C.E. Taylor)pp. 375-398. Academic Press, London and New York.

Taylor, O.C. and F.M. Eaton 1966. Suppression of plant growth by NO_2. Physiol. Plant. 41: 132-135.

Taylor, O.C.and D.C. MacLean 1970. Nitrogen oxides and the peroxyacyl nitrates. In: Recognition of air pollution injury to vegetation: A pictorial atlas (Eds.J.S. Jacobson and A.C. Hill) pp. E1-E14. Air Pollut. Contr. Assoc., Pittsburgh.

Taylor, A.L. and J.N. Sasser 1978. Biology, Identification and Control of Root-Knot Nematodes (Meloidogyne species).A cooperative publication of the Dept. of Plant Pathol., North Carolina State Univ. and United State Agency for International Development. North Carolina State University, Raleigh, N.C. 111 pp.

Taylor, A.L., J.N. Sasser and L.A. Nelson 1982. Relationship of climate and soil characteristics to geographical distribution of Meloidogyne species in agricultural soils. A cooperative publication of the Dept. of Plant Pathology, North Carolina State University and United State Agency of International Development. North Carolina University, Raleigh, N.C. 66 pp.

Thakre, R. and A.L. Aggarwal 1985. Plant community responses to thermal power station emissions. Energy Environ. Mont. 1: 21-31.

Thomas, M.D. 1951. Gas damage to plants. Ann. Rev. Plant Physiol. 2: 293-322.

Thomas, M.D., R.H. Hendricks, T.R. Collier and G.R. Hill 1943. The utilization of sulphate and sulphur dioxide for the nutrition of alfalfa. Plant Physiol. 18: 345-371.

Thomas, M.D., R.H. Hendricks, L.C. Bryner and G.R. Hill 1944. A study of the sulphur metabolism of wheat, barley and corn using radio active sulphur. Plant Physiol. 19: 227-244.

Ting, I.P. and W.H. Dugger Jr. 1968. Factors affecting ozone sensitivity and susceptibility of cotton plants. J. Air Pollut. Contr. Assoc. 18: 810-813.

Tingey, D.T. 1974. Ozone induced alterations in the metabolite pools and enzyme activities of plants. In: Air pollution effects on plant growth (Ed. M. Dugger). Am. Chem. Soc. Symp. Ser. 3: 150 pp.

Tingey, D.T. and U. Blum 1973. Effects of ozone on soybean nodules. J. Environ. Qual. 2: 341-342.

Todd, G.W. 1958. Effect of ozone and ozonated 1-hexene on respiration and photosynthesis of leaves. Plant Physiol. 33: 416-420.

Todd, G.W. and B. Probst 1963. Changes in transpiration and photosynthetic rates of various leaves during treatment with ozonated hexene or ozone gas. Physiol. Plant.16: 57-65.

Treshow, M. 1975. Interaction of air pollutants and plant disease. In: Responses of plants to air pollution (Eds. J.B. Mudd and T.T. Kozlowski) pp. 307-334. Academic Press, New York.

Unsworth, M.H. and J. Black 1981. Stomatal responses to pollutions In: Stomatal physiology (Eds. P.G. Jarvis and T.A. Mansfield) pp. 187. Cambridge Univ. Press, London and New York.

Unsworth, M.H., P.V. Biscoe and H.R. Pinckney 1972. Stomatal response to sulphur dioxide. Nature 239: 458.

Van Gundy, S.D. 1985. Ecology of Meloidogyne spp. Emphasis on environmental factors affecting survival and pathogenicity In: An advanced treatise on Meloidogyne vol. I: Biology and control (Eds. J.N. Sasser and C.C. Carter) pp. 177-182. A cooperative publication of Department of Plant Pathology, N.C.S.U., Raleigh and U.S.A.I.D.

Vargo, R.H., E.J. Pell and S.H. Smith 1978. Induced resistance to ozone injury of soybean by tobacco ring spot virus. Phytopathology 68: 715-719.

Varshney, C.K. and J.K. Garg 1979. Plant responses to sulphur dioxide pollution. CRC Crit. Rev. Environ. Contr. pp. 27-49.

Vincent, J.M. 1977. Rhizobium: General Microbiology. In: A treatise on nitrogen fixation. Section III: Biology (Eds. R.W.F. Hardy and W.S. Silver) pp. 277-366. John Wiley and Sons, New York and London.

Waldron, J.K. 1978. Effects of soil drenches and simulated rain application of sulphuric acid and sodium sulphate on the nodulation and growth of legumes. M.S. Thesis, North Carolina State University, Raleigh. 53 pp.

Wallace, H.R. 1966. The influence of moisture stress on development, hatch and survival of eggs of Meloidogyne javanica. Nematologia 12: 57-69.

Wallace, H.R. 1987. Effects of nematode parasites on photosynthesis. In: Vistas on nematology (Eds. J.A. Veech and D.W. Dickson) pp. 253-259. Society of Nematologists, Inc., Hyatisville, Morlyland, USA.

Wardojo, S., M.J. Hijink and M. Oostenbrink 1963. Damage to white clover by inoculation of Heterodera trifolii, Meloidogyne hapla and Pratylenchus penetrans. XVth Int. Symp. Crop Prot. pp. 101.

Weber, D.E., R.A. Reinert and K.R. Barker 1979. Ozone and sulphur dioxide effects on reproduction and host parasite relationships of slected plant-parasitic nematodes. Phytopathology 69: 624-628.

Weidensaul T.C. and S.L. Darling 1979. Effects of ozone and sulphur dioxide on the host-pathogen relationship of scotch pine and Schirrhia acicola. Phytopathology 69: 939-941.

Weinstein L.H., D.C. McCune, A.L. Aluisio and P. Van Leuken 1975. The effect of sulphur dioxide on the incidence and severity of bean rust and early blight of tomato. Environ. Pollut. (A) 9: 145-155.

Wertheim, F.S. and L.E. Craker, 1987. Acid rain and pollen germination in corn. Environ. Pollut. (A) 48: 165-172.

Weitheim, F.S. and L.E. Craker, 1988. Effects of acid rain on corn silks and pollen germination. J. Environ. Qual. 17: 135-138.

Whitmore, M.E. and T.A. Mansfield 1983. Effect of long term exposure to SO_2 and NO_2 on Poa pratense and other grasses. Environ. Pollut.(A)31:217-235.

Wilcox-Lee, D. and R. Loria, 1987. Effects of nematode parasitism on plant-water relation. In: Vistas on ematology (Eds. J.A. Veech and D.W. Dickson) pp. 260-261. Society of Nematologists, Inc. Hyattsville, Maryland, USA.

Winner, W.E. and H.A Mooney 1980. Effect on vegetation. In: Air pollution (Ed. A.S. Stern) vol. 6, pp. 247-350. Academic Press, New York.

Wood, F.A. 1968. Source of plant pathogenic air pollutants. Phytopathology 58: 1075-1084.

Wood, T. and F.H. Bormann 1974. The effects of an artificial acid mist upon the gorwth of Betula alleghaniensis Britt. Environ. Pollut. (A) 7: 259-268.

Wong, M.H. and J.W.C.Wong 1986. Effects of flyash on soil microbial activity. Environ. Pollut. (A) 40: 127-144.

Wukasch, R.T. and G. Hofstra, 1976. Ozone and Botrytis spp.interaction in onion leaf dieback: field studies. J. Am. Soc. Hort. Sci. 102: 543-546.

Wukasch, R.T. and G. Hofstra 1977. Ozone and Botrytis interactions in onion leaf die back: open top chamber studies. Phytopathology 67: 1080-1084.

Wyss, H.R. and C. Brunold 1980. Regulation of adenosin 5-phosphosulphate sulphotransferase by sulphur dioxide in primary leaves of beans (Phaseolus vulgaris). Physiol. Plant. 50: 161-165.

Yomo, H. 1958. Studies on the barley malt. The sterilization of barley seeds and amylase formation of separated embryos and endosperms. Hakko Kyokai Schi. 16: 444.

Yomo, H. 1960a. Studies of the α-amylase activating substance. IV. On the amylase activating action of gibberellin. Hakko Kyokai Shi. 18: 600.

Yomo, H. 1960b. Studies of the amylase activating substance. V. Purification of the amylase activating in the barley malt and its properties. Hakko Kyokai Shi. 18: 603.

Zaidi, S.H., A.Z. Amani, M.H. Farooqui and A.K.M. Ghouse 1979. Leaf apidermal structure of Croton bonplandianus Baill in relation to air pollution. Proc. Symp. Eknvrion. Biol. pp. 239-242.

Zielger, I. 1975. The effect of SO_2 pollution on plant metabolism. Residue Rev. 56: 79-105.

Zimmerman, P.W. and W. Crocker, 1934. Toxicity of air containing sulphur dioxide gas. Contrib. Boyce Thompson Inst. 6: 455-470.